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AFRPL TR-83-013 AD:

AD A131008

User's Manual
for the period
1 February 1979 to
31 December 1981

Particle Impact Erosion

Volume IV: User's Manual

Erosion Prediction Procedure for Rocket Nozzle Expansion Region

May 1983

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F04611-79-C-0012

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prepared for the: **Air Force Rocket Propulsion Laboratory**
Air Force Space Technology Center
Space Division, Air Force Systems Command
Edwards Air Force Base,
California 93523

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFRPL-TR-83-0013	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
PARTICLE IMPACT EROSION
Volume IV: User's Manual - Erosion Prediction Procedure for Rocket Nozzle Expansion Region

5. TYPE OF REPORT & PERIOD COVERED
User's Manual
1 Feb 1979 to 31 Dec 1981

6. PERFORMING ORG. REPORT NUMBER
LAX-FR-01

7. AUTHOR(s)
J. D. Mockenhaupt and J. H. Wickman

8. CONTRACT OR GRANT NUMBER(s)
F04611-79-C-0012

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Aerojet Strategic Propulsion Company
P. O. Box 15699C
Sacramento, CA 95813

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Air Force Rocket Propulsion Laboratory, MKBS
Edwards Air Force Base, CA 93523

12. REPORT DATE
May 1983

13. NUMBER OF PAGES
101

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Solid Rocket Motors
Nozzle Erosion
Two-Phase Flow
Particle Impingement
Aluminum Oxide
Erosion Prediction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Attached

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ABSTRACT

An experimental and analytical program was conducted to develop a methodology to predict total recession, including the contribution by particulate impact erosion, in solid propellant rocket nozzles. The program was divided into two phases. Under Phase I, a methodology was developed for predicting recession due to particle impact erosion in the expansion (exit cone) region of nozzles. This phase was performed by the Aerojet Strategic Propulsion Company (ASPC) under a subcontract to the Aerotherm Division of Acurex Corporation. Under Phase II, a methodology was developed for predicting recession due to erosion coupled with ablation in the entrance and throat regions of nozzles. This phase was performed by Aerotherm.

For the supersonic expansion region methodology (Phase I), the TD2P computer code, contained within the Interim Solid Performance Program (ISPP), was chosen for predicting the two-phase flow. The TD2P code is used to predict the location of particle impingement on the nozzle exit cone wall and the impact conditions. Also, it was used in conjunction with erosion test data to generate mechanical erosion models. Data for erosion models were obtained from one series of tests in the Dust Erosion Tunnel (DET) at the Arnold Engineering Development Center (AEDC) and a second series of tests in small rocket motors at ASPC. Two independent mechanical erosion models were developed. The first was derived using the "G-law" approach, while the second was formulated to represent the physical phenomena occurring during the erosion process.

For the subsonic entrance and throat region methodology (Phase II), a variety of tests were used in modeling particle impact erosion -- particle (droplet) breakup; aluminum (Al) and aluminum oxide (Al_2O_3) chemical reactions with carbon; and subsonic erosion tests using Al and Al_2O_3 impacting a carbon surface. The subsonic erosion was modeled using the "G-law" approach. Two computer codes were developed: (1) the Chamber Flowfield Code (CFC) for predicting particle impact conditions at the nozzle wall, and (2) the Charring Material Ablation-Erosion (CMAE) code for computing the contributions of erosion and ablation to recession.

Both the Phase I and Phase II recession prediction methodologies were demonstrated by comparing predictions to data from rocket motor test firings having known or suspected particle impact erosion. Program results are reported in four volumes, as follows:

- Volume I: Recession Prediction Methodology for Rocket Nozzle Entrance and Throat Regions
- Volume II: Erosion Model Development (Expansion Region)
- Volume III: User's Manual -- Chamber Flowfield Code (CFC) and Charring Material Ablation-Erosion (CMAE) Code
- Volume IV: User's Manual -- Erosion Prediction Procedure for Rocket Nozzle Expansion Region

SUMMARY

An experimental and analytical program was conducted to develop a methodology to predict total recession, including the contribution by particulate impact erosion, in solid propellant rocket nozzles. The program was divided into two phases. Under Phase I, a methodology was developed for predicting recession due to particle impact erosion in the expansion (exit cone) region of nozzles. This effort was performed by the Aerojet Strategic Propulsion Company (ASPC) under a subcontract to the Aerotherm Division of Acurex Corporation. Under Phase II, a methodology was developed for predicting recession due to erosion coupled with ablation in the entrance and throat regions of nozzles. This effort was performed by Aerotherm. Results from this program are reported in four separate volumes, as follows:

- Volume I: Recession Prediction Methodology for Rocket Nozzle Entrance and Throat Regions
- Volume II: Erosion Model Development (Expansion Region)
- Volume III: User's Manual — Chamber Flowfield Code (CFC) and Charring Material Ablation-Erosion (CMAE) Code
- Volume IV: User's Manual — Erosion Prediction Procedure for Rocket Nozzle Expansion Region

The remainder of this summary provides a brief overview of the recession prediction methodologies developed for the nozzle expansion region (reported in Volume II) and for the nozzle entrance and throat regions (reported in Volume I).

Nozzle Expansion Region

A procedure was developed for predicting the erosion that occurs in a solid rocket nozzle exit cone when aluminum oxide (Al_2O_3) particles in the flow impact the nozzle wall in the supersonic region downstream of the nozzle throat. This procedure consists of a two-phase flow solution and two independent mechanical erosion models. These models calculate the nozzle wall erosion patterns in carbon-carbon and bulk graphite materials as a function of the impinging particle flow properties, the impact angle, and the nozzle wall material properties.

An empirical 'G-law' erosion model was developed for nozzle expansion regions from Dust Erosion Tunnel (DET) test data and small solid motor firing data. Specimens of carbon-carbon, bulk graphite, and tantalum/tungsten were exposed to particle-laden test gases. A debris layer shielding erosion model was also developed for the expansion region. In contrast to the empirical G-law, this model was formulated to represent the fundamental physics of the erosion process.

The TD2P two-phase flow code contained in te Interim Solid Performance Program (ISPP) was modified to incorporate the above two erosion models. This version of TD2P constitutes the methodology for predicting particle impact conditions at the walls of nozzle exit cones and the resulting wall erosion. Predictions were made using both erosion models for various solid rocket motor test firings where erosion occurred. Predictions using the G-law model were generally acceptable relative to test results, providing the particle flow and impact conditions were within the range covered by the DET and small motor experiments. Predictions using the debris layer model were also generally satisfactory, but not as accurate as G-law predictions when particle impact conditions were within the DET and small motor test range. However, the debris layer model was the most accurate for conditions outside the experimental range.

Nozzle Entrance and Throat Regions

A methodology was developed for predicting the total recession, including particle impact erosion, for the entrance and throat regions of solid rocket nozzles. Major program efforts included the development of a motor chamber-nozzle flowfield code and a model for describing the erosion process in the subsonic regions of the nozzle.

The Fully Coupled Transonic (FCT) two-phase flow module of the Solid Performance Prediction (SPP) program was modified to compute particle trajectory crossovers and particle impact conditions at the nozzle wall. Also, the calculation domain was extended forward to account for the motor chamber and propellant grain, including mass injection from the grain. However, flow within the submerged region of nozzles remains to be included. This modification is referred to as the Chamber Flowfield Code (CFC).

Empirical subsonic erosion models were developed for predicting recession due to the impact of aluminum (Al) and Al_2O_3 particles. Models were constructed in the form of a G-law with two components: mechanical erosion due to mechanical mass removal and chemical erosion due to particle-surface chemical reactions. However, the models are based on bulk graphite data and provide only rough estimates for the erosion of carbon-carbon composites. The Charring Material Ablation (CMA) code was modified to include these models in predictions of recession resulting from ablation and erosion. This modification is designated the Charring Material Ablation-Erosion (CMAE) code.

The recession prediction methodology for subsonic flow regimes was demonstrated for two motor firings having suspected particle erosion in the entrance region of carbon-carbon composite nozzles. The demonstration results substantiated the prediction of the onset of particle impact for the two motors. However, recession predictions using the bulk graphite erosion model provided only a rough estimate of material removed.

Although not currently included in the recession prediction methodology, particle breakup in nozzle entrance and throat regions was modeled in terms of Bond number and nondimensional time. This model was based upon cold-flow data, and its applicability to hot-firing conditions has not been demonstrated.

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FIGURE LIST

TABLE LIST

1.0 INTRODUCTION

This Users Manual contains the information needed to prepare input for, run, and interpret results from two separate computer codes which calculate erosion due to particle impact. The two codes are:

1. A modified version of the Interim Solid Performance Program (ISPP), which computes the two-phase flow in a rocket nozzle and thus the particle impact conditions, if any. These conditions are then used to calculate the resulting nozzle wall erosion.

2. A stand-alone code, PIEROS, in which the particle impact conditions must be input before the erosion is calculated.

Both codes contain two distinct particle impact erosion models: 1) an empirical model based solely on experimental data, and 2) a debris-layer model that represents the actual physical processes. An option is available for saving the particle impact conditions calculated during an ISPP run to be used as subsequent input to the stand-alone PIEROS code. The various options available for using these codes are represented in a flow diagram presented in Figure C-1.

When using the ISPP to calculate the particle flow field in a nozzle, the erosion resulting from any particle impact at the nozzle wall is automatically calculated with the empirical erosion model and the results printed at each impact location. Since the debris-layer erosion model requires substantially more computer time (usually 3 to 5 minutes), its use during the ISPP run is left as an option. To allow subsequent use of the debris-layer model (and/or the empirical model with different impact parameters), the particle impact conditions calculated with the ISPP can be saved on a unit specified by the input parameter ISAVE.

The stand-alone particle impact erosion code, PIEROS, can be used independently from the ISPP code by having the particle impact conditions input

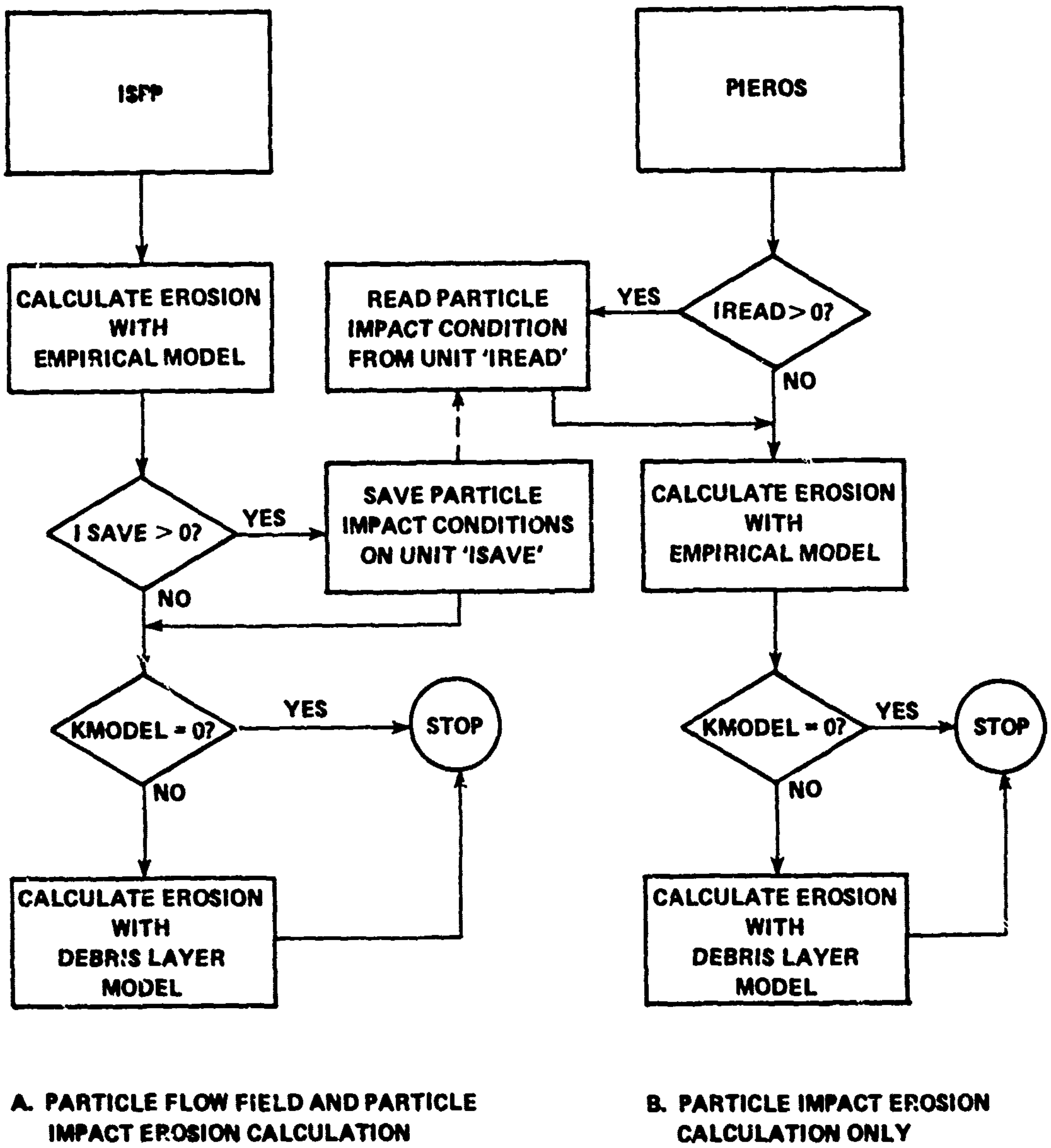

Figure C-1. Particle Impace Erosion Calculation Options

directly, or it can use the conditions saved during a previous ISPP run. As with the ISPP, particle impact erosion in PIEROS is calculated automatically with the empirical erosion model, with use of the debris-layer model optional.

1.1 INTERFACE WITH ISPP

ISPP is a collection of computer codes designed to calculate the delivered specific impulse of a solid rocket motor. The overall flow diagram for the ISPP is shown in Figure C-2. A complete ISPP run would include the following calculations:

1. A one-dimensional, shifting-equilibrium nozzle expansion for a specified propellant chemistry with the ODE code,

2. A solid propellant grain design and corresponding internal ballistics as a function of time with the BAL code,

3. A one-dimensional, finite-rate nozzle expansion with the ODK code,

4. A two-dimensional, two-phase nozzle expansion with the TD2P code,

5. A turbulent boundary layer solution along the nozzle wall with the TBL code.

However, for particle impact erosion purposes only the TD2P code is required, possibly in conjunction with the ODE code to provide the flow properties for TD2P. Fortunately, ISPP is structured to allow this particular combination, as indicated by the asterisks in Figure C-2.

It is not intended in this Users Manual to include the details of using the ISPP codes, which are covered in Reference C-1. However, these areas which have a direct bearing on the particle impact erosion calculations will be discussed. It is assumed that the user already has the ISPP operational on a

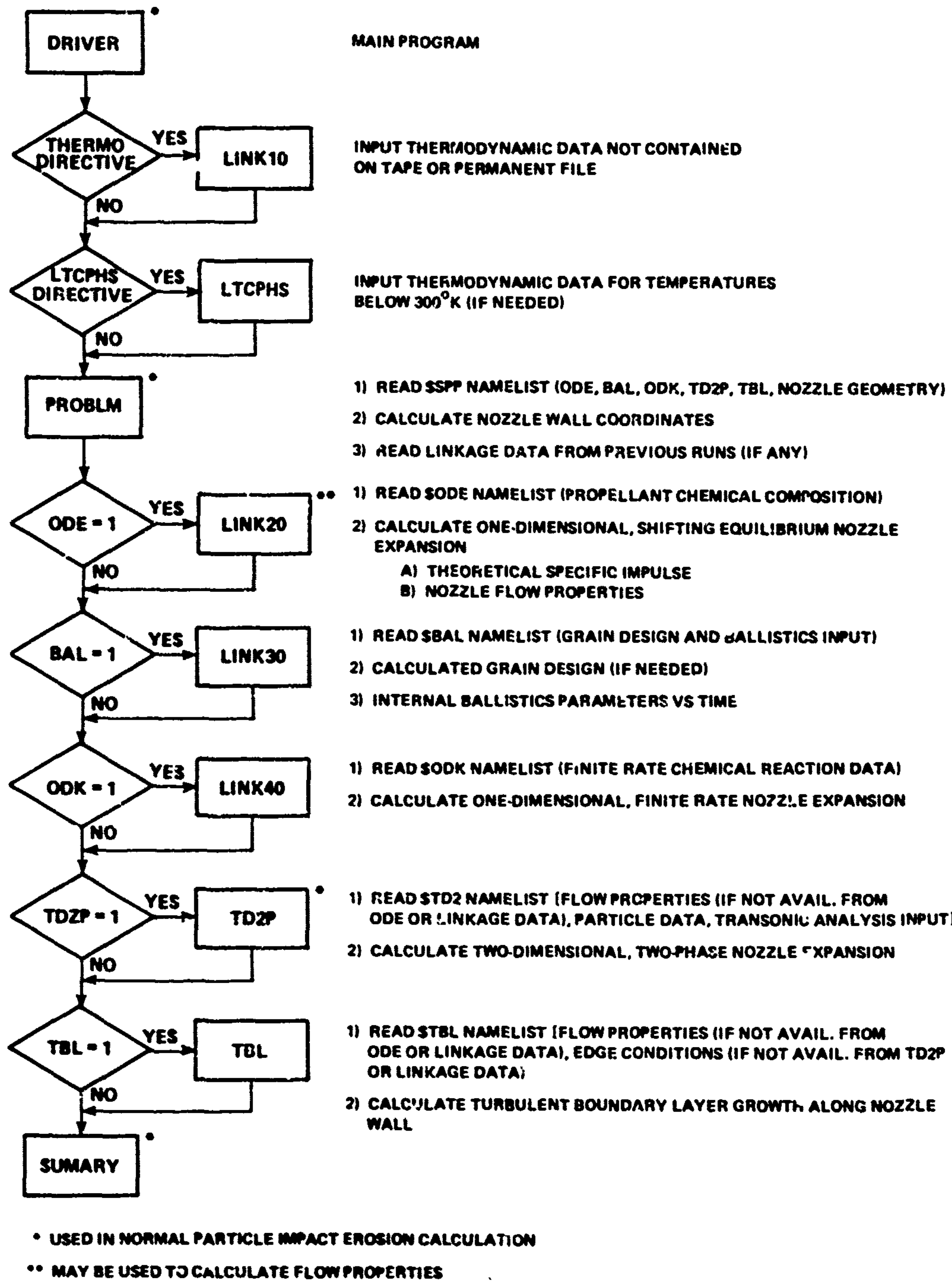

Figure C-2. ISPP Flow Diagram

local computer system and that the modified and new subroutines needed for the particle impact erosion calculations can simply be linked to the existing main program and associated subroutines.

As shown in Figure C-2, a typical ISPP calculation for particle impact erosion would require input from the $SPP and $TD2 namelists. The nozzle geometry and the option parameters (ODE, BAL, ODK, TD2P, and TBL) are input in the $SPP namelist, and the flow properties, particle data, and transonic analysis parameters in the $TD2 namelist. If the ODE code is to be used for calculating the flow properties, instead of inputting them directly, then the necessary data is input in the $ODE namelist, preceded by a list of reactants specifying the propellant chemical composition (see Reference C-1 for details).

To integrate the particle impact erosion calculations into the TD2P two-phase flow nozzle solution, four existing subroutines were modified and four new subroutines added. A flow diagram showing the most significant subroutines used in this solution is given in Figure C-3.

The controlling subroutine, TD2P, first calls INPTD2 to read input from the $TD2 namelist, and then DIST to calculate the particle size-versus -mass distribution. Two transonic solutions are available for the two-phase flow through the nozzle inlet and throat, the Approximate Transonic Analysis (ATA) or the Fully-Coupled Transonic (FCT). The choice of transonic solution is determined by the parameters ATA and FCT from the $TD2 namelist. The transonic solution terminates just downstream of the throat, generating a start line across the nozzle for the method-of-characteristics (MOC) solution used for the supersonic flow in the nozzle exit cone.

After the transonic solution, the TD2P subroutine calls N2MAIN, which in turn calls N3MAIN to integrate the thrust across the startline, and CNTRL for the MOC solution. At each wall solution point in the MOC solution, CNTRL calls the subroutine THRST to integrate the thrust along the wall from the previous wall solution point, and the subroutine IMPNG to check for particle impingement at the wall.

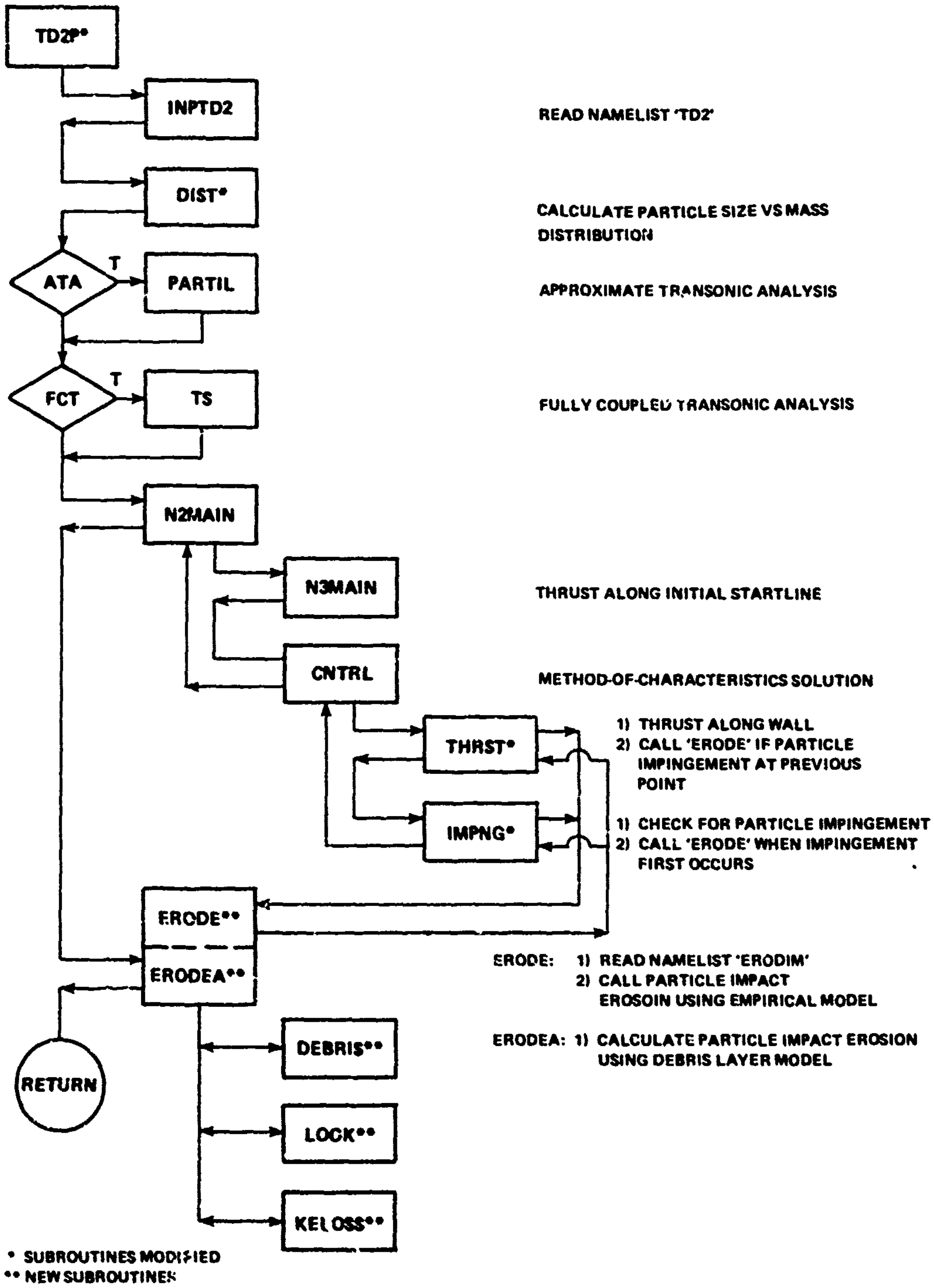

Figure C-3. TD2P Flow Diagram

To include the particle impact erosion calculations, modifications were made to the TD2P, DIST, THRST, and IMPNG subroutines, and the ERODE subroutine, including the entry ERODEA, was added along with supporting subroutines DEBRIS, LOOK, and KELOSS.

To allow the calculated particle impact conditions to be saved on unit ISAVE, it was also necessary to make a single change to the main program DRIVER. This change terminated the ISPP run at the conclusion of each case, allowing the file created on unit ISAVE to be closed.

1.1.1 Modifications to Existing Subroutines

1.1.1.1 DIST Subroutine

Originally the particle size-vs-mass distribution could be either input directly or calculated by the DIST subroutine, with the mass mean diameter and standard deviation either input or calculated internally. The calculated distribution, however, was limited to equal mass increments; e.g., if 5 particle sizes were requested, the sizes were calculated with each representing 20 percent of the particle mass. For particle impact erosion, it was found that a better representation of the smaller particle sizes was needed, which could only be obtained by requesting a large number of particle sizes with a corresponding large increase in computer run time. Thus, the DIST subroutine was modified so that unequal mass increments could be input and the corresponding particle sizes determined. For example, 6 particle sizes representing particle mass fractions of .01, .02, .04, .08, .15, and .70 can now be used.

1.1.1.2 IMPNG and THRST Subroutines

The IMPNG subroutine was modified to make the initial call to the particle impact erosion subroutine ERODE when particle impingement is first detected. On the first call to ERODE, the namelist $ERODIN is read with the data required for the erosion calculations. The THRST subroutine was modified to call ERODE at subsequent wall points downstream of the first impact point.

The use of IMPNG and THRST to call ERODE is repeated for each particle size that impacts the nozzle wall.

1.1.1.3 TD2P Subroutine

The fourth existing subroutine modified was TD2P to print a summary of the calculated particle impact erosion at the conclusion of the MOC solution, and to call the entry ERODEA within the ERODE subroutine to calculate the erosion with the debris-layer model, if desired.

1.1.2 <u>New Subroutines</u>

The ERODE subroutine, new to ISPP, reads the $ERODIN namelist and calculates the erosion depth at each point along the wall where particle impact occurs. The calculated erosion results are then immediately printed. The particle flow conditions at each impact point are saved for subsequent use by the debris-layer model and, if desired, are written on a specified output file.

If the debris-layer model is to be used for calculating erosion, the entry ERODEA within ERODE is called by TD2P after the nozzle flow solution has been completed. The debris-layer model requires an axial distribution of particle flow properties from the initial impact point to the nozzle exit. Three subroutines, also new to ISPP, are called from ERODEA: DEBRIS, which calculates flow conditions within the debris layer, LOOK, an interpolation routine, and KELOSS, which calculates the kinetic energy lost for each collision within the debris layer.

To summarize, any current ISPP code can be updated to include the particle impact erosion calculates by linking the updated DRIVER main program and the following modified (m) or new (n) subroutines to the existing code: TD2P(m), DIST(m), THRST(m), and IMPNG(m), ERODE(n), DEBRIS(n), LOOK(n), and KELOSS(n).

2.0 <u>INPUT DESCRIPTION</u>

2.1 ISPP OPTION

2.1.1 <u>ISPP Input</u>

2.1.1.1 $SPP Namelist

No changes have been made to the input information contained within the $SPP namelist (see Reference C-1). To run only the TD2P module:

ODE = 0.
BAL = 0.
ODK = 0.
TBL = 0.
TD2P = 1.

If the ODE is to be used for calculating the flow properties for TD2P:

ODE = 1

If the results from a previous ODE calculation are to be used:

ODE = 2

The only other input data required from the $SPP namelist is the nozzle geometry (pages 2-1 through 2-20 in Reference C-1). If plots of the method of characteristics solution along with the gas or particle streamlines are desired, the plot data described in pages 2-25 through 2-30 in Reference C-1 should be input. The particle streamline plots can be useful in evaluating the particle impact results.

2.1.1.2 $TD2 Namelist

For a particle impact erosion calculation, the $TD2 namelist input described on pages 2-70 through 2-80 of Reference C-1 remains essentially the same. The only change is the additional option now available for calculating the particle size-vs-mass distribution. This option is invoked by inputting the particle mass fractions WPWT (page 2-74) <u>without</u> the corresponding particle radii R (page 2-73). Note that the number of WPWT values input must correspond to NPG, the number of particle size groups, and that the summation of the WPWT values must equal 1.0.

2.1.2 <u>Particle Impact Erosion Input</u>

The additional input required for particle impact erosion calculations is contained in the namelist $ERODIN, which follows the $TD2 namelist. The input parameters are described below:

<u>Parameter</u>	<u>Description</u>	<u>Units</u>	<u>Default Value</u>
$ERODIN			
<u>For Debris-Layer Erosion Model:</u>			
ST	Yield shear stress of target material	psi	2200.
RHOTAR	Target material density	lbm/cu-ft	120.
FACTOR	Coefficient in single particle erosion equation (C in equation 4-b in report)	none	6.782
EXPFAC	Velocity exponent in single particle equation (C2 in equation 4-b in report)	none	2.0
CD	Particle drag coefficient within debris layer	none	5.0
MAXY	Maximum number of finite elements (calculation terminates when exceeded)	none	1000
IEMAX	Maximum number of consecutive steps allowed with calculated erosion rate less than 0.01 mil/sec	none	100

ERMIN	Minimum erosion rate (calculated with empirical model) that must be exceeded before debris-layer model calculation begins	mil/sec	0.
XPRINT	Axial distance print increment in debris-layer model (set to zero to delete debris layer print, except for summary)	inches	0.

<u>For Empirical Erosion Model:</u>

$$\dot{y} = CONSTE\ (V_p)^{EXPV}\ (\rho_p V_p)^{EXPRHV}\ (\theta_p)^{EXPTH}\ (d_p)^{EXPD1[1-\exp(-EXPD2/\rho_p V_p)]}$$

where $\dot{y}$ = erosion rate in mil/sec,

V_p = particle velocity in ft/sec,

$\rho_p V_p$ = particle mass flux in $lbm/ft^2 \cdot sec$,

θ_p = impact angle in degrees,

d_p = particle diameter in microns.

CONSTE	Coefficient in empirical erosion equation	mil/sec	2.22
EXPV	Particle velocity exponent in empirical equation	none	6.4
EXPRHV	Particle mass flux exponent in empirical equation	none	1.0
EXPTH	Impact angle exponent in empirical equation	none	2.5
EXPD1	Diameter first exponent in empirical equation	none	1.0
EXPD2	Diameter second exponent in empirical equation	none	6.6

<u>General Input:</u>

TIME	Time period for calculating total erosion depth	sec	-
KMODEL	= 0 to bypass debris-layer model calculations	none	0

ISAVE	Unit on which particle impact conditions are to be saved. See description under IREAD in Section 2.2 for parameters saved. (Set to zero if conditions are not to be saved.)	none	0
XRHOP	Particle density correction factor if time particle size-vs-mass distribution is not used (e.g., a single particle size run using a size other than the mass mean)	none	1.0
$END			

2.2 PIEROS STAND-ALONE CODE

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2.2.1 <u>$DATAIN Namelist</u>

Parameter	Description	Units	Default Value
$DATAIN			
RT	Nozzle throat radius	inches	-
ZWMAX	Ratio of maximum nozzle length/RT	none	-
SMP	Particle material density	lbm/ft^3	-
HPS	Particle enthalpy at solidification	ft^2/sec^2	-
ZW	Ratio of nozzle length at impact point/RT	none	-
UG	Gas axial velocity at impact point	ft/sec	-
VG	Gas radial velocity at impact point	ft/sec	-
RHG	Gas density at impact point	lbm/ft^3	-
JMAX	Total number of particle sizes present at impact point	none	1
DP(J)	Particle diameter at impact point (J = 1 to JMAX)	microns	-
UP(I)	Particle axial velocity at impact point (J = 1 to JMAX)	ft/sec	-

VP(I)	Particle radial velocity at impact point (J = 1 to JMAX)	ft/sec	-
HP(J)	Particle enthalpy at impact point (J = 1 to JMAX)	ft^2/sec^2	-
RHP(J)	Particle density at impact point (J = 1 to JMAX)	lbm/ft^3	-
IREAD	Unit number from which previously saved data is to be read. Data includes all of the above parameters from RT to RHP(J). (Set to zero if all data is contained in namelist.)	none	0

$END

2.2.2 <u>$ERODIN Namelist</u>

$ERODIN

Same parameters as $ERODIN namelist described in Section 2.1.2.

$END

Data for additional impact points may be input in successive $DATAIN namelists, but the $ERODIN namelist is not repeated. For example, data for three impact points would be input in the following sequence:

```
TITLE
$DATAIN
      Data for first impact point
$END
$ERODIN
      Erosion model parameters
$END
$DATAIN
      Data for second impact point
$END
```

```
$DATAIN
      Data for third impact point
$END
```

3.0 OUTPUT DESCRIPTION

3.1 ISPP OPTION

3.1.1 Empirical Erosion Model Results

With the ISPP option, the nozzle two-phase flow field is calculated, and whenever particle impact is detected at the nozzle wall, the resulting erosion is immediately calculated with the empirical erosion model. The erosion results are then printed before the nozzle solution continues, and a typical output is shown in Figure C-4.

At the initial impact point for a particular particle size group, the first line printed begins "PARTICLE IMPACT,...", followed by the wall coordinates (nondimensionalized by the throat radius) and nozzle area ratio at that point. This message is then followed by a list of the mass-averaged properties of the impinging particles; i.e., the particle velocity, mass flux, diameter, and impact angle. A mass-averaged property, $\bar{a}$, for N number of different particle size groups is defined as:

$$\bar{a} = \frac{\sum_{n=1}^{N} (\rho_p V_p)_n \, a_n}{\sum_{n=1}^{N} (\rho_p V_p)_n}$$

where $(\rho_p V_p)_n$ is the particle mass flux for particle size group n.

Following the particle mass-averaged properties, the results of the empirical erosion model in terms of the calculated erosion rate, the maximum erosion depth, and the axial location of the minimum depth are printed. As

```
07/26/82  09:49:37 MA      0425AA410    MA              10     300                                    DATE 072682          PAUL    37

60  4  4.97567  9.76431   3.3980  3070.0 10153.3  17.005  .48385   .00649  .01342   .03465   .0000      .00  2
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     3     .146182+00     .999309+04     .179791+02     .317665+04     .194287-01     .575470-05     .879506-05
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     2     .831400-01     .100544+05     .177680+02     .314120+04     .973638-02     .286572-05     .292279-05
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60  5  5.01848  9.79621   3.4172  3055.0 10185.7  17.033  .48148   .00651  .01351   .00000  1.8407  290.08  2
60  4  5.01399  9.80003   3.4168  3055.0 10184.3  17.076  .48148   .00647  .01345   .00509   .0000      .00  2
     1     .409360-01     .101031+05     .175630+02     .311089+04     .509295-02     .149518-05     .209520-05
60  5  5.02434  9.81535   3.4193  3053.1 10188.7  17.033  .48118   .00648  .01347   .00000  1.8411  290.09  2
60  4  5.00706  9.81069   3.4122  3058.3 10176.2  17.044  .48201   .00645  .01330   .01471   .0000      .00  2
     1     .405868-01     .100947+05     .175270+02     .311461+04     .495097-02     .144708-05     .209520-05
     2     .813034-01     .100592+05     .177382+02     .313827+04     .975410-02     .285075-05     .292279-05
60  4  5.02021  9.81968   3.4162  3055.5 10183.5  17.004  .48156   .00648  .01345   .00507   .0000      .00  2
     1     .429415-01     .101054+05     .175479+02     .310946+04     .507424-02     .149154-05     .209520-05
60  5  5.03021  9.83450   3.4213  3051.2 10191.7  17.033  .48089   .00645  .01342   .00000  1.8415  290.15  2
60  4  5.03642  9.83936   3.4185  3053.4 10186.8  17.005  .48123   .00645  .01340   .00508   .0000      .00  2
     1     .422553-01     .101076+05     .175323+02     .310305+04     .507945-02     .148750-05     .209520-05
60  5  5.03608  9.85367   3.4234  3049.3 10194.7  17.033  .48059   .00643  .01338   .00000  1.8418  290.21  2
60  4  4.96495  9.83191   3.3855  3079.0 10130.9  16.855  .48527   .00640  .01318   .07331   .0000      .00  3
     1     .409560-01     .100518+05     .173785+02     .313473+04     .493078-02     .142092-05     .209520-05
     2     .813187-01     .100164+05     .175916+02     .315866+04     .978016-02     .281740-05     .292279-05
     3     .143551+00     .997149+04     .178392+02     .318692+04     .194304-01     .559738-05     .379506-05
     4     .266920+00     .989474+04     .182091+02     .324186+04     .391642-01     .112821-04     .495892-05
60  4  5.00163  9.84446   3.4055  3063.1 10164.4  16.959  .48276   .00641  .01327   .03464   .0000      .00  2
     1     .407391-01     .10083A+05     .174586+02     .311921+04     .499664-02     .144894-05     .209520-05
     2     .812732-01     .100482+05     .176699+02     .314301+04     .100079-01     .290211-05     .292279-05
     3     .144118+00     .100031+05     .179177+02     .317062+04     .196361-01     .569419-05     .379506-05
60  4  5.01974  9.85038   3.4183  3057.3 10178.0  16.956  .48184   .00644  .01336   .01465   .0000      .00  2
     1     .425247-01     .100995+05     .174972+02     .311167+04     .492180-02     .143951-05     .209520-05
     2     .839122-01     .100639+05     .177080+02     .313536+04     .971570-02     .283585-05     .292279-05
60  4  5.03264  9.85904   3.4207  3051.4 10190.0  17.006  .48091   .00642  .01336   .00508   .0000      .00  2
     1     .416083-01     .101099+05     .175171+02     .310663+04     .505469-02     .148405-05     .209520-05

*******************************************************

PARTICLE IMPACT, WALL (R,Z)=  5.04196   9.87285      AREA RATIO=    25.421
*******************************************************

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =    9.673 :

   VELOCITY = 10109.92 FT/SEC, MASS FLUX =   .263 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE =  .484 DEG.

CALCULATED EMPIRICAL EROSION RATE:

      .081 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .325 MILS AT Z/RT =    9.882

60  3  5.04196  9.87285   3.4255  3047.4 10197.6  17.033  .48029   .00649  .01333   .00509  1.8422  290.27  2
     1     .421710-01     .101099+05     .175171+02     .310663+04     .503442-02     .148405-05     .209520-05
60  5  5.04784  9.89205   3.4275  3045.5 10200.6  17.033  .47999   .00635  .01329   .00510  1.8426  290.33  2
     1     .416043-01     .101123+05     .175033+02     .310516+04     .509589-02     .142027-05     .209520-05
60  3  5.03293  9.89011   3.4177  3053.3 10184.4  16.353  .48121   .00635  .01327   .01467   .0000      .00  2
     1     .415891-01     .101034+05     .174667+02     .310915+04     .494104-02     .143257-05     .209520-05
     2     .822553-01     .100686+05     .176773+02     .313248+04     .975158-02     .282151-05     .292279-05
```

Figure C-4: ISPP Output at Initial Impact Point

shown in Figure C-5, a triangular erosion pattern is assumed, which is defined by the maximum erosion depth and the impact angle relative to the nozzle wall surface. The maximum erosion depth is simply the calculated erosion rate multiplied by the exposure time input in the namelist $ERODIN. If the erosion pattern reaches the nozzle exit plane before the maximum depth is reached, the depth at the exit plane Y_e is printed instead of the maximum depth Y_m. The erosion depth at the exit plane is defined as:

$$Y_e = Y_m \frac{(Z_e - Z_i)}{(Z_m - Z_i)}$$

where Z_i, Z_e, and Z_m are the axial locations of the impact point, the nozzle exit plane, and the maximum erosion depth, respectively.

Downstream of the initial impact point for any one particle size group, the erosion calculation is repeated at each wall point in the nozzle solution. The typical printout in Figure C-6 shows the particle mass-averaged properties and calculated erosion follow the thrust and mass flow decrements that are integrated from the initial impact of the first particle size group to hit the wall.

When a different particle size group first impacts the wall, the "PARTICLE IMPACT....." printout is repeated prior to the listing of the mass-averaged properties and calculated erosion.

At each wall point where the mass-averaged properties of the impinging particles are printed, the properties are stored internally as a function of the wall point axial coordinate for subsequent use in the debris layer erosion model. Since this erosion model requires the axial distribution of the impacting particle properties, instead of point values as used by the empirical model, calculations with the debris layer model begin only after the nozzle solution is completed.

At the conclusion of the nozzle flow solution, a summary table of erosion depth versus the nozzle axial cordinate Z/R_t, as shown in Figure C-7, is printed following the usual ISPP "Particle Impingement Summary". At each

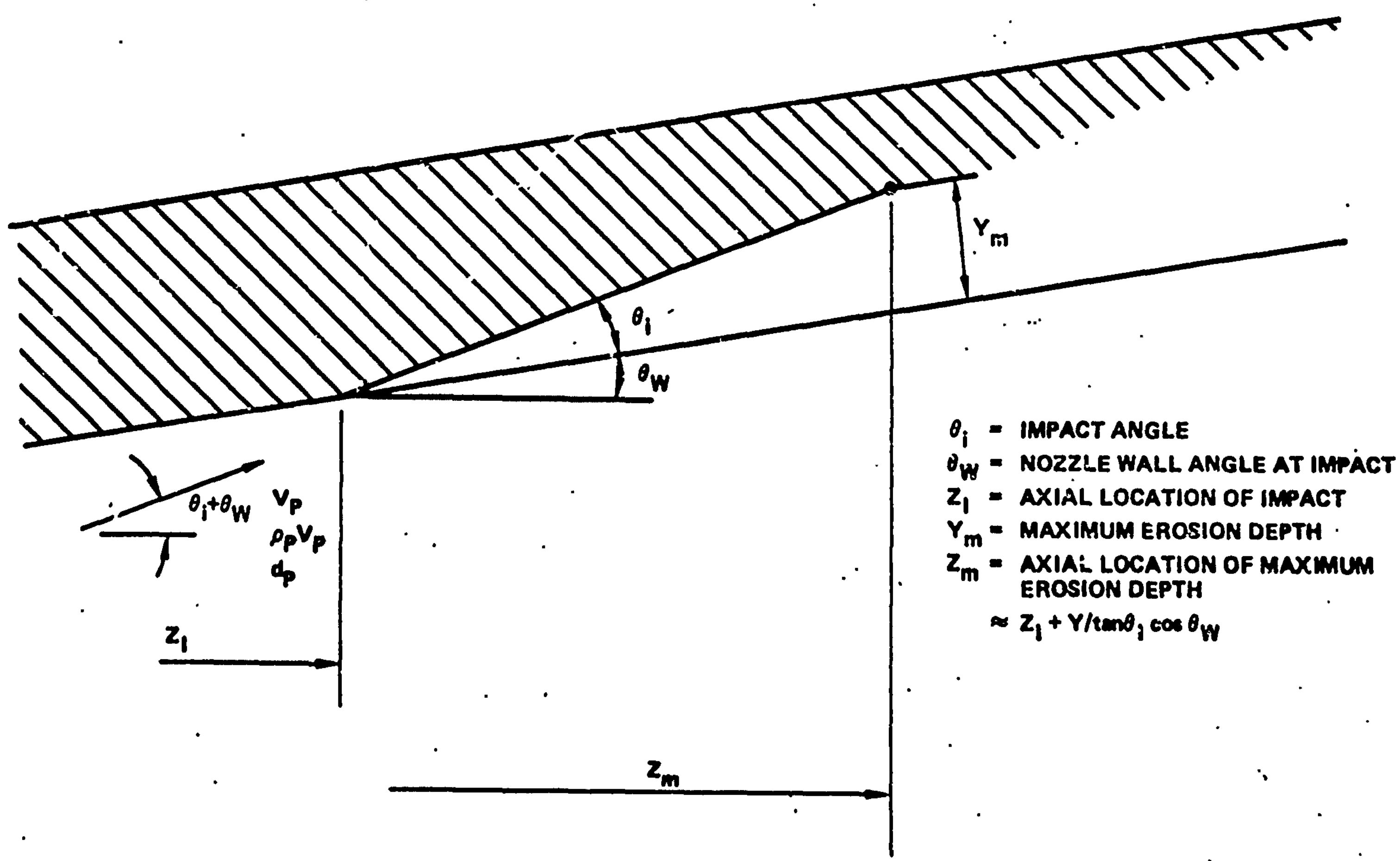

Figure C-5: Calculated Erosion Geometry

```
07/26/82  09:49:57 MA       0425AA410     MA                  10     300                                                  DATE 072682         PAGE    98

  62  4  5.60924 12.08905   3.5389  2937.3 10543.3  15.437  .46294   .00462  .00998   .14422   .0000      .00  3
        1     .318900-01    .102586+05     .159167+02      .299916+04     .485863-02      .105550-05     .209520-05
        2     .634562-01    .102195+05     .161055+02      .302593+04     .957901-02      .208978-05     .292279-05
        3     .109934+00    .101747+05     .163110+02      .305590+04     .189921-01      .414834-05     .379506-05
        4     .199455+00    .101032+05     .166175+02      .320521+04     .375631-01      .821666-05     .495892-05
        5     .395159+00    .997687+04     .170790+02      .323895+04     .731455-01      .159576-02     .670406-05
  62  4  5.67527 12.09179   3.5776  2908.9 10405.7  15.651  .45846   .00464  .01012   .07221   .0000      .00  2
        1     .321029-01    .103176+05     .160941+02      .297172+04     .490494-02      .108519-05     .209520-05
        2     .643201-01    .102776+05     .162794+02      .299867+04     .971529-02      .214945-05     .292279-05
        3     .112261+00    .102309+05     .164816+02      .302893+04     .191213-01      .423047-05     .379506-05
        4     .203666+00    .101601+05     .167886+02      .307490+04     .384670-01      .851050-05     .495892-05
  62  5  5.70510 12.13978   3.5893  2900.2 10424.0  15.651  .45708   .00465  .01012   .03403  1.8809   296.36  3
        1     .327834-01    .103365+05     .161158+02      .296219+04     .494708-02      .109436-05     .209520-05
        2     .653038-01    .102963+05     .162995+02      .298923+04     .976808-02      .216052-05     .292279-05
        3     .113682+00    .102490+05     .164998+02      .301966+04     .193131-01      .427250-05     .379506-05
  62  4  5.69044 12.14214   3.5821  2905.1 10411.8  15.641  .45785   .00461  .01006   .07223   .0000      .00  2
        1     .316993-01    .103229+05     .160723+02      .296840+04     .490630-02      .107871-05     .209520-05
        2     .636592-01    .102829+05     .162569+02      .299540+04     .971692-02      .213657-05     .292279-05
        3     .111231+00    .102352+05     .164582+02      .302571+04     .191238-01      .420452-05     .379506-05
        4     .201933+00    .101653+05     .167636+02      .307165+04     .384840-01      .846120-05     .495892-05
  62  5  5.71837 12.18715   3.5934  2896.6 10429.4  15.651  .45652   .00459  .01005   .03406  1.8815   296.47  2
        1     .320542-01    .103405+05     .160917+02      .295953+04     .495263-02      .108811-05     .209520-05
        2     .642034-01    .103002+05     .162751+02      .298660+04     .977920-02      .214843-05     .292279-05
        3     .112074+00    .102531+05     .164748+02      .301705+04     .193256-01      .424659-05     .379506-05
  62  4  5.71319 12.21774   3.5872  2900.7 10418.9  15.589  .45716   .00457  .00999   .07210   .0000      .00  2
        1     .319408-01    .103309+05     .160387+02      .296349+04     .489867-02      .106965-05     .209520-05
        2     .638703-01    .102907+05     .162227+02      .299055+04     .969960-02      .211795-05     .292279-05
        3     .111258+00    .102440+05     .164228+02      .302091+04     .190832-01      .416799-05     .379506-05
        4     .201488+00    .101732+05     .167264+02      .306680+04     .384117-01      .838756-05     .495892-05
  62  5  5.73824 12.25821   3.5965  2893.8 10433.5  15.576  .45608   .00456  .01000   .03394  1.8826   296.63  3
        1     .328107-01    .103466+05     .160552+02      .295560+04     .495732-02      .107888-05     .209520-05
        2     .651199-01    .103063+05     .162384+02      .298271+04     .974774-02      .213003-05     .292279-05
        3     .112981+00    .102592+05     .164373+02      .301316+04     .192561-01      .420774-05     .379506-05
  62  4  5.73593 12.29349   3.5920  2876.6 10425.4  15.528  .45652   .00453  .00993   .07194   .0000      .00  2
        1     .324022-01    .103387+05     .160040+02      .295865+04     .489099-02      .106122-05     .209520-05
        2     .643884-01    .102984+05     .161879+02      .298575+04     .965186-02      .210079-05     .292279-05
        3     .111677+00    .102518+05     .163870+02      .301614+04     .190506-01      .413351-05     .379506-05
        4     .201562+00    .101809+05     .166889+02      .306200+04     .385198-01      .831445-05     .495892-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1         ALFA*THRUST DECREMENTS=      -.94279       MASS FLOW DECREMENTS=      -.01032
PARTICLE GROUP 2         ALFA*THRUST DECREMENTS=     -1.66426       MASS FLOW DECREMENTS=      -.01820
PARTICLE GROUP 3         ALFA*THRUST DECREMENTS=     -2.13804       MASS FLOW DECREMENTS=      -.02340

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  12.329 :

    VELOCITY = 10291.52 FT/SEC, MASS FLUX =   .822 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.009 MICRONS, IMPACT ANGLE =  .711 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

          1.880 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        7.519 MILS AT Z/RT =  12.480

  62  5  5.75807 12.32936   3.6026  2888.5 10441.5  15.576  .45525   .00451  .00990   .03399  1.8836   296.79  2
        1     .317147-01    .103926+05     .160188+02      .295168+04     .494553-02      .106964-05     .209520-05
        2     .634857-01    .103122+05     .162019+02      .297883+04     .975332-02      .211165-05     .292279-05
        3     .110614+00    .102652+05     .164000+02      .300930+04     .192763-01      .416915-05     .379506-05
```

Figure C-6: ISPP Output Downstream of Initial Impact Point

```
MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.408 :
   VELOCITY = 10673.60 FT/SEC, MASS FLUX =  1.430 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.005 DEG.
CALCULATED EMPIRICAL EROSION RATE:
      15.875 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .969 MILS AT Z/RT =  22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.417 :
   VELOCITY = 10673.89 FT/SEC, MASS FLUX =  1.429 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.003 DEG.
CALCULATED EMPIRICAL EROSION RATE:
      15.801 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .376 MILS AT Z/RT =  22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.421 :
   VELOCITY = 10674.01 FT/SEC, MASS FLUX =  1.429 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.
CALCULATED EMPIRICAL EROSION RATE:
      15.767 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .085 MILS AT Z/RT =  22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.422 :
   VELOCITY = 10674.05 FT/SEC, MASS FLUX =  1.429 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.
CALCULATED EMPIRICAL EROSION RATE:
      15.762 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .007 MILS AT Z/RT =  22.422
```

PARTICLE IMPACT EROSION SUMMARY
FROM EMPIRICAL MODEL

Z/RT	EROSION DEPTH (MILS)
9.8728	.00
9.8823	.32
10.4354	.24
10.7189	1.66
11.3736	1.63
11.6455	8.03
12.4797	7.52
13.1945	34.48
13.9092	32.25
15.0482	31.41
16.6254	140.84
17.3424	124.12
18.5287	107.27
1[illegible].7505	91.85

Figure C-7: Summary Output for Erosion Profile Calculated with Empirical Model

axial location in the "Particle Impact Erosion Summary", a check is made to determine the maximum erosion depth resulting from any overlapping triangular erosion patterns. Such overlapping can occur if the impact angle and/or maximum erosion depth associated with each triangular pattern decreases with axial distance.

3.1.2 Debris Layer Model Results

If KMODEL in the $ERODIN namelist is greater than zero, the calculation of nozzle wall erosion with the debris layer model begins right after the summary of the empirical erosion model results is printed. As shown in Figure C-8, the first page of the debris layer model output contains the input parameters from the $ERODIN namelist, followed by the axial distribution of mass-averaged particle properties at the nozzle wall impact points. This latter table is also saved in unit ISAVE, if ISAVE was given a value greater than zero in $ERODIN. The axial lengths in this table, however, are in inches and are not measured from the nozzle throat, but from the start of the debris layer calculation. This initial position is either the location of the first particle impact point, or if ERMIN is greater than zero in $ERODIN, the location where the empirical erosion model calculated the erosion rate to be equal to ERMIN.

Following the input information, the debris layer model results are presented as a function of axial length. The second, third, fourth, and sixth columns in Figure C-8 contain calculated debris layer parameters. The second column lists the percentage of particles approaching the nozzle wall that penetrate the debris layer and impact the wall. The sixth column shows the average number of collisions experienced by each approaching particle within the debris layer. Columns three and four contain the average axial velocity and density of the particles that form the debris layer. The calculated erosion rate due to the particles penetrating the debris layer is then presented in the fifth column.

Using the axial distribution of calculated erosion rates, and the assumed erosion pattern (Figure C-5), a summary table of erosion depth versus

PARTICLE IMPACT EROSION MODEL

INPUT DATA

TOTAL EROSION TIME(SEC)= 4.00
PARTICLE DENSITY(LBM/FT**3)= 247.70
FINITE ELEMENT AXIAL LENGTH(MICRONS)= 200.
GAS VELOCITY(FPS) = 10194.13

TARGET DENSITY(LBM/FT**3)= 120.00
AXIAL PRINT INCREMENT(IN)= 2.00
DRAG COEFFICIENT = 5.00

TARGET SHEAR YIELD STRESS(PSI)= 2200.00
LAST AXIAL PRINT LOCATION(IN)= 44.39
GAS DENSITY(LB/FT**3) = .00318000

FACTOR= .6782+01 EXPFAC= 2.000

AXIAL LENGTH (IN)	PARTICLE DIAMETER (MICRONS)	PARTICLE VELOCITY (FPS)	INCIDENT FLUX DENSITY (LBM/CU.FT.)	IMPACT ANGLE (DEG)
.000	.20102+01	10215.74	.80519-04	.723
4.529	.25458+01	10263.88	.16325-03	.905
13.498	.33153+01	10339.96	.25314-03	1.215

CALCULATED AXIAL DISTRIBUTION OF EROSION RATES

AXIAL LENGTH (IN)	% OF PARTICLES PENETRATING DEBRIS LAYER	DEBRIS LAYER VELOCITY (FPS)	DEBRIS LAYER DENSITY (LBM/FT**3)	EROSION RATE (MILS/SEC)	AVE.NO.OF PARTICLE COLLISIONS
.00	97.8	10215.	.00008852	17.7	1
2.00	.3	9947.	.00012152	2.3	5
4.00	.0	10101.	.00015451	.9	10
6.00	.0	10162.	.00016325	.1	16
8.00	.0	10190.	.00016325	.0	23

******* ZERO EROSION RATE CALCULATED FOR 100 CONSECUTIVE STEPS *******

PARTICLE IMPACT EROSION SUMMARY
FROM EROSION MODEL

Z/RT	EROSION DEPTH (MILS)
11.4860	.00
12.8654	70.63
12.1420	9.30
12.5266	3.46
12.9732	.58
13.4576	.05

FIN

Figure C-8: Debris Layer Erosion Model Output

axial distance is then prepared and printed. In this summary, the axial distance is the same (Z/R_t) as that used in the empirical model summary table to allow direct comparison of results.

3.2 PIEROS STAND-ALONE CODE

3.2.1 Empirical Erosion Model Results

With the PIEROS stand-alone erosion prediction code, the mass-averaged particle properties, the resulting erosion rate and depth, and the axial location of both the impact point and the maximum erosion depth are printed for each impact location. The impacting particle properties are input either in the $DATAIN namelist or read from unit IREAD. The output format, as shown in Figure C-9, is the same as that used within the ISPP nozzle flow solution. A summary table of erosion depth versus Z/R_t follows, which is also identical in form to that in the ISPP.

3.2.2 Debris Layer Model Results

The output from the debris layer erosion model contained within the PIEROS code is identical to the debris layer results obtained with ISPP (Figure C-8).

3.3 ERROR MESSAGES AND DIAGNOSTICS

For description of the error message and diagnostics that can be obtained from the ISPP, the user is referred to Section 5 of Reference C-1. The erosion calculations contain only a few messages that might appear in the output, and these are described below:

MESSAGE	EXPLANATION OR CORRECTIVE ACTION
ERROR IN NAMELIST ERODIN	An input parameter contained within the $ERODIN namelist does not match a variable name in Section 2.1.2. Check input data.

```
                         PARTICLE IMPACT EROSION IN A NOZZLE EXIT CONE


        S0001 TEST CASE

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =   9.873 :
   VELOCITY = 10109.92 FT/SEC, MASS FLUX =   .163 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE =  .484 DEG.
CALCULATED EMPIRICAL EROSION RATE:
         .081 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       .323 MILS AT Z/RT =   9.882

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  10.428 :
   VELOCITY = 10172.40 FT/SEC, MASS FLUX =   .151 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE =  .439 DEG.
CALCULATED EMPIRICAL EROSION RATE:
         .061 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       .244 MILS AT Z/RT =  10.435

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  10.678 :
   VELOCITY = 10171.62 FT/SEC, MASS FLUX =   .428 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.610 MICRONS, IMPACT ANGLE =  .568 DEG.
CALCULATED EMPIRICAL EROSION RATE:
         .415 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      1.658 MILS AT Z/RT =  10.719

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  11.333 :
   VELOCITY = 10237.34 FT/SEC, MASS FLUX =   .399 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.612 MICRONS, IMPACT ANGLE =  .571 DEG.
CALCULATED EMPIRICAL EROSION RATE:
         .408 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      1.633 MILS AT Z/RT =  11.374

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  11.486 :
   VELOCITY = 10216.36 FT/SEC, MASS FLUX =   .907 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.010 MICRONS, IMPACT ANGLE =  .715 DEG.
CALCULATED EMPIRICAL EROSION RATE:
        2.007 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      5.028 MILS AT Z/RT =  11.646

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  12.329 :
```

Figure C-9: PIEROS Output for Empirical Erosion Model

WARNING: LIQUID PHASE PARTICLES PRESENT	The tempeature of at least one impinging particle size group is above the melting temperature of the particle material. See Section 4 for recommendations for these conditions.
ZERO EROSION RATE CALCULATED FOR XXXX CONSECUTIVE STEPS	The debris layer erosion model calculated erosion rates (less than 0.01 mil/sec) for XXXX consecutive debris layer elements and the run was terminated. This prevents excessive computer time usage and is controlled by the input parameter IEMAX in the $ERODIN namelist.
EXCEEDED XXXX ELEMENTS	The maximum number of debris layer elements used in the debris layer erosion calculation was exceeded and the run was terminated. This prevents excessive computer time usage and is controlled by the input parameter MAXY in the $ERODIN namelist.
TABLE ERROR IN LOOK	An axial location was not contained within the input table of particle conditions versus length and the run was terminated. Check input data.
ERROR IN NAMELIST DATAIN	An input parameter contained within the $DATAIN namelist for the PIEROS code does not match a variable name in Section 2.2.1. Check input data.

4.0 RECOMMENDED PRACTICES AND GUIDELINES

4.1 ISPP

For general recommended practices and guidelines for using ISPP, the user is referred to Section 4 of Reference C-1. A few additional recommendations, however, can be made to help give more reasonable particle erosion resuts.

4.1.1 Particle Size-vs-Mass Distribution

It is strongly recommended that the low end of the particle size-vs-mass distribution be well represented since the majority of the particle impact will be produced by the small sizes. The ISPP has been modified to allow this distribution to be specified by inputting mass fractions for which corresponding particle sizes will be calculated internally. For cases run to date, the six particle size distribution corresponding to WPWT = .01, .02, .04, .08, .15, and .70 has proven to be successful. In larger nozzles, some problems in the nozzle flow solution may be experienced with the smallest particles. In such cases, the distribution can be modified slightly by using five sizes corresponding to WPWT = .02, .04, .08, .16, and .70, or four sizes corresponding to WPWT = .04, .08, .16, and .72. Note that the sum of the WPWT values must equal 1.0.

The ISPP computer run time increases almost linearly with the number of particle size groups used. Therefore, in some cases it may be worthwhile to make a single particle ISPP run with a small particle size representative of the lower end of the size-vs-mass distribution to determine if particle impact will occur in a given nozzle. Single particle results have correlated fairly well with those for multi-particle runs as far as impact location is concerned. However, to obtain reasonable calculated erosion results, it is necessary that the proper mass fraction be assigned to the single particle size by using the variable XRHOP (see Section 2.1.2).

4.1.2 TD2P Control Parameters

Two control parameters input within the $TD2 namelist that are important to the particle trajectory, and thus impingement, calculations, are DHIT and DCR. DHIT specifies the maximum separation distance that is allowed between a particle streamline and nozzle wall before impact is assumed to occur. Too large a value for DHIT forces an artificial particle impact at an axial location too far upstream. On the other hand, too small a value can make the impact location calculation too dependent on small numerical errors in the flow field solution, particularly at low impact angles. DCR specifies the maximum separation distance that is allowed between adjacent particle streamlines for different particle size groups before the streamlines are assumed to cross. Too large a value for DCR can artificially shift layer particles closer to the wall, greatly changing any subsequent impact conditions. Like DHIT, too small a value for DCR can lead to numerical difficulties. Based on past experience with numerous TD2P calculations, it is recommended that the values of 0.005 and 0.010 be used for DHIT and DCR, respectively, for nozzles with throat radii in the 1.5 to 6.0 inch range. For larger nozzles, these parameters, which are actually separation distances divided by the throat radius, should be reduced to maintain approximately the same physical separation distances.

Other TD2P control parameters that can affect the calculated particle trajectories are NILP, the number of points along the MOC startline, and both DR and DL, the maximum width between solution points along a right-running and left-running characteristic, respectively. Too small a value for NILP and too large a value for DR and DL can lead to solution inaccuracies and possible failure, while vary large computer run times can result with a large NILP and small DR and DL. It was found in studies conducted during this program that the default values of NILP = 40 and DR = DL = 0.1 gave the best results, and are therefore recommended.

4.1.3 Transonic Solution

Of the two transonic solutions available in the ISPP for the two-phase flow in the nozzle inlet and throat region, the ATA and FCT, the FCT

would definitely be preferred since the ATA is limited to conical inlet shapes. The FCT, however, is a more complex solution requiring greater amounts of input preparation and computer run time, and leading to more potential problems in achieving a successful solution. If the ATA is used, the nozzle conical inlet angle and upstream wall radius of curvature should be selected to best represent the actual nozzle inlet geometry. For nonsubmerged nozzles, inlet angles of 30^{o} or less should be used to give representative particle trajectories, and for submerged nozzles, a 60^{o} inlet angle is recommended.

4.2 EROSION CODES

4.2.1 Use of Empirical and Debris Layer Erosion Models

The debris layer erosion model can use significant amounts of computer time for cases where relatively large number of collisions occur within the debris layer. It is therefore recommended when using the ISPP option that the debris layer calculations not be made in the same run as the nozzle flow solution by setting KMODEL=0 in the $ERODIN namelist, and that the particle impact conditions be saved by setting ISAVE in $ERODIN to the unit number on which the data is to be written. In this manner, the results of the empirical erosion model can be examined to determine if debris layer calculations are necessary. If so desired, the debris layer model can then be run with the PIEROS code and the data from unit ISAVE.

In evaluating the results from the empirical erosion model, the calculated erosion rates would be expected to be valid if the particle flow and impact conditions fall within the following ranges:

Particle velocities from 4000 to 11000 ft/s,
Particle mass fluxes less than 20 lbm/s·ft^2,
Particle diameters less than 10 μm,
Particle temperatures less than the particle material melting temperature, and
Impact angles less than 10^{o}.

For particle flow and impact conditions outside the above ranges, the debris layer model should be used, unless the particle mass flux is below 1.0 $lbm/s \cdot ft^2$. If the particles are in the liquid phase, a first order correction to the erosion rates calculated by the debris layer model can be made by dividing the rates by a factor of 20.

4.2.2 Nozzle Wall Material

The erosion models were developed primarily for carbon-carbon and graphite nozzle wall materials. For the empirical model, a first-order correction for carbon-phenolic materials based on material density has been derived, but this correction would not be expected to be valid for other materials. The debris layer model does use the yield shear stress and density of the target material (ST and RHOTAR in the $ERODIN namelist), and this theoretically could give representative erosion results for other materials. However, the debris layer model results have only been evaluated for the carbon-carbon and graphite materials to date.

4.2.3 Scale Effects

Correlation studies have shown that the erosion models gave the best rsults for nozzles with throat radii in the range from 1.5 to 6.0 inches. For smaller nozzles, the erosion was usually overpredicted, and for larger nozzles underpredicted. This effect is thought to be related more to the two-phase flow solution rather than the erosion models themselves.

4.2.4 Erosion Model Input Parameters

As shown in Section 2.1.2, default values based on previous correlations are contained within the erosion codes for most of the input parameters. The only parameter that always needs to be input is TIME, the time period used to convert the calculated erosion rates to erosion depths. However, the default values can be overridden if different options are designed (such as saving data on unit ISAVE), or if the correlation with a specific set of erosion data can be improved by adjusting one or more of the parameters for either of the erosion models.

5.0 SAMPLE CASES

Three sample cases are presented to illustrate the use of the particle impact erosion models. The first is a complete ISPP run with the complete nozzle flow solution and the erosion calculated at each wall point where impingement occurs. The particle flow conditions at the impact points were saved for later input to the stand-alone code PIEROS, which is illustrated in the second sample case. The third sample case also used PIEROS, but with all the particle conditions input through the namelist $DATAIN.

For all three cases, the SD001 motor and nozzle configuration was used since it experienced severe particle erosion in the nozzle exit cone.

5.1 CASE 1: ISPP OPTION WITH EROSION MODELS

Sample Case 1 includes a full two-phase nozzle flow solution with particle impact erosion calculated with both the empirical and debris layer model within the same run.

The control cards used for this run on a UNIVAC 1108 computer are shown in Table C-1. In this case, the gas and particle properties were input directly; but if the properties are to be calculated with the ODE code, additional control cards are required to assign a thermodynamic property data file and equate it to unit 25 (see Section 2.10 of Reference C-1). At the completion of the ISPP run, the impacting particle conditions were written on unit 10 and saved as an element in a user file with the @ELT and @ADD cards. Note that to create this element, the ISPP run cannot terminate on an error message. This was the reason the main program DRIVER has to be slightly modified.

The input data for Case 1 is listed in Table C-2. Note that in the $SPP namelist, only the TD2P flag is nonzero, and only the nozzle geometry data is included. In the $TD2 namelist, all the required gas and particle properties are input in the first four lines. If the ODE were to be used to calculate these properties, the ODE flag in the $SPP namelist would be set to 1, and additional input included before the $TD2 namelist. A third option can

```
@ASG,AX      SPP.              Assign program file for ISPP
@ASG,T     10.                 Assign temperory file for unit 10 (i.e. ISAVE)
@XQT    SPP.SPPA               Execute absolute element SPPA in program file SPP.


        DATA


@ELT,IL    SPP.DATA10          Create element DATA10 in program
@ADD,P 10.                     file SPP. (or any other file) with data written
                               on unit 10 (i.e. ISAVE) during program execution
@FIN
@@
```

Table C-1: UNIVAC 1108 Control Cards for Sample Case 1

```
TITLE SD001
SPP
 $SPP
 ODE=0.,TD2P=1.,TBL=0.,
 INLET=0,RWTU=2.16,THETAI=30.,
 IWALL=4,RWTD=1.33,THETA=30.8,THE=12.5,
 RS(2)=7.315,11.214,15.942,20.167,24.726,28.137,31.945,
 ZS(2)=7.490,15.602,27.366,40.296,56.713,70.452,87.02,
 NWS=8,KZNORM=3.881,
 RSI=3.881,
 $END
 $TD2
 TGO=6345.,GMGO=.6342-4,CAPN=.67756,CPL=11288.,
 TPM=4167.,EPM=6.3752,UGM=7951.,DHM=1.25+7,PR=.4617,
 CPSOL=8149.7,
 WPWST=.45762,
 DL=.1,DR=.1,THIW=1.,
 NILP=40,
 NPG=6,WPWT=.01,.02,.04,.08,.15,.70,
 PC=800.,
 DHIT=.005,
 DCR=.01,
 $END
 $ERODIN
 TIME=4.,
 ISAVE=10,
 $END
```

Table C-2: Input Data for Sample Case 1

be called by setting ODE equal to 2 and reading in the property data from a file created during a previous ODE run. For details on using the ODE = 1 and ODE = 2 options, the user is referred to Reference C-1.

The $TD2 namelist in Table C-2 also includes the recommended values for the control parameters DL, DR, NILP, DHIT, and DCR, and the recommended particle mass fractions to be used for calculating the particle size distribution. The ATA transonic solution for conical inlets was used for this case. However, if the FCT transonic solution was desired, additional input would be included in the $TD2 namelist (see Reference C-1).

In this case, most of the default values for the erosion model input parameters were used, and thus only the erosion time period and the ISAVE unit number for serving the calculated particle conditions at impact are input in the namelist $ERODIN.

Selected portions of the output for Case 1 are presented in Table C-3. The first 21 pages of this table show the standard ISPP output, including the input from the SPP namelist, the gas and particle properties, the calculated nozzle contour, the calculated particle size-vs-mass distribution, the MOC start line determined from the ATA transonic solution, and some of the MOC supersonic two-phase flow solution. Page 57 shows the output where the first particle impact is detected for Particle Group 1 with a 1.278 micron diameter, and the resulting erosion calculated with the empirical erosion model. The following page shows the erosion output for the same particle size at a subsequent wall point. The results for the first impact point for Particle Group 2 (1.782 micron diameter) are then shown on the following page (page 59). The calculated erosion at this point is based on the mass-averaged properties of the combined particle Groups 1 and 2. On subsequent pages, the appearance of the words 'PARTICLE IMPACT, WALL (R,Z) = ...,' indicates the initial impact point for a different particle size group.

The nozzle flow solution for Case 1 is concluded on page 77, followed by a PARTICLE IMPINGEMENT SUMMARY that shows the net mass flow and thrust decrements associated with each particle size group that impacted the wall

within the nozzle. The calculated erosion depths from the empirical model are then summarized as a function of the nondimensional axial distance from the throat, Z/R_t.

The input data for the debris layer erosion model then follows on page 79. The table of impacting particle conditions versus length was stored internally and also written on unit 10, corresponding to the ISAVE value in the $ERODIN namelist. The debris layer results are shown on page 80, the last page of Table C-3. In this case, the density of the particles in the calculated debris layer was large enough to protect the nozzle wall downstream of the second print location, resulting in the calculation being terminated when a zero (actually less than 0.01 mil/sec) erosion rate was calculated for 100 consecutive steps. Termination for more or less consecutive steps can be controlled by inputting the desired maximum number of steps as IEMAX in the $ERODIN namelist.

The last portion of the Case 1 output is a summary of erosion depths calculated with the debris layer model as a function of Z/R_t. Comparing this table with the corresponding table containing the empirical erosion model results on page 78, it can be seen that the debris layer model apparently overpredicts the shielding effect for this case, since the calculated erosion is much less than the empirical model results, which correlate well with data.

```
07/26/82  09:49:57 MA     0325AA410     MA              10    300                                  DATE 072682        PAGE     2
                              **** SOLID PERFORMANCE PROGRAM(SPP) - VERSION 4****
      WRITEN BY SOFTWARE AND ENGINEERING ASSOCIATES,INC FOR THE AIR FORCE ROCKET PROPULSION LABORATORY


TITLE SD001
SPP
                 NOZZLE GEOMETRY SPECIFICATION
            NOZZLE THROAT DATA
     RSI= INITIAL THROAT RADIUS                                  =    3.8810 INCHES OR     9.8577 CM
     RWTU=  UPSTREAM THROAT RADIUS OF CURVATURE RATIO            =    2.1600
     RWTO= DOWNSTREAM THROAT RADIUS OF CURVATURE RATIO           =    1.3300
     RSDOT= NOZZLE THROAT EROSION RATE                           =     .0000 MILS/SEC OR      .0000 MM/SEC
     TBURN= MOTOR BURN TIME                                      =     .0000 SECONDS
            NOZZLE INLET DATA
     INLET=0, CONICAL INLET ONLY
     THETAI=   30.0000 DEG                       RWTU=    2.1600
     RI=     .0000                               ZI=      .0000
            EXHAUST NOZZLE DATA
     IWALL=4, TABULAR EXHAUST NOZZLE CONTOUR-(SPLINE OPTION)
     THETA=   30.8000 DEG                        RWTO=    1.3300
     THE=   12.5000DEG
             I      ZS          RS
             1     .68102     1.18758
             2    1.92991     1.88492
             3    4.02010     2.88946
             4    7.05128     4.10770
             5   10.38289     5.19634
             6   14.61275     6.37104
             7   18.15303     7.24994
             8   22.42206     8.23113
     R2NORM=   3.88100                       FSUBM=    .00000
     AEAS=   1.0000                          KNOZ=    0
     NNOZ=   1
```

TABLE C-3: Output for Sample Case 1

```
          NASUB=    0
     I         ASUB
     1         .0000
          NASUP=    0
     I         ASUP
     1         .0000
      ICE=    0                                  PFLAG=    .00000
      DMM=       .000                            ASIG=    .20000
      ALFAAP=    .00000                          KDOT=    .00000
      RHOA=   2.08000                            XK=    .00000
      XL=       .00                              VEMPTY=        .00
      WPROP=       .00                           KHPROP=    .00000
      INST=        0                             WEX=       .00
      ICEFLG=    0                               FAL1=    .18002
      DELH1=    9960.0                           CP1=    .85920
      TC1=   6289.00                             DELH2=        .0
     I              FUBTAB            ETATAB
     1              .00000            1.00000
     2              .05555             .99074
     3              .11111             .98117
     4              .16667             .97130
      ITE=    0                                  KODE=    0
      TAMB=       .00
      ODE=   0.   RAL=   0.      ODK=   0.      IREQ=    0      TU2P=   1.      TBL=   0.
      INP=    3
          MODULES TO BE EXECUTED ARE
                TD2P
```

```
**************************************************************************************************
              TWO DIMENSIONAL - TWO PHASE FLOW LOSS MODEL (TD2P)

                        SD001

                     INPUT CONDITIONS
          PC=          800.000          TGO=         6345.000
          LSTAR=          .000          NPG=                6
          GMGO=       .6342-04          CAPN=          .67756
          WPWGT=        .45762          WT FRAC=       .31395
          RRT=         2.16000          RWTD=         1.33000
          THID=       30.00000          THJW=        30.80000
          IWALL=             4          PGFLG=         .00000
          CPL=         11288.0          XMLW=       101.96000
          UGS=            .000          TPS=             .000
          VEMPTY=           .0          WPROP=             .0
          RHPROP=       .00000          SMP=          186.000
          ALFA=          .3000          DL=            .10000
          DR=           .10000          DTWI=         3.50000
          DHIT=         .00500          EW=            .00100
          IMAX=              5          N1=              1000
          N2=                1          NTBL=              15
          XITBL=         .0000

G(I)=     .1131629+01 E(I)=       .6375311+01
CPG =     .1598875+05   G GAS= .1181890+01 HCAP =     .2460635+04
CPS =     .8149700+04 HPS =      .3395980+08 HPL =      .4645980+08 HPO =     .7104506+08  PR =    .4617000+00
RHOGO=    .2273989+00   B =      .1101689+01  BS =      .1181929+01 GSB =     .1142583+01
          UGM=        7951.000          TPM=        4167.000
          EPM=          6.3752          DHM=       1.2500+07
```

IWALL = 4 OPTION SPECIFIED

CONTOURED NOZZLE OPTION SELECTED, WALL TABLE IS

I	PWRS(I)	PWZS(I)	WALL SLOPE
1	.11876+01	.58102+00	.59612+00
2	.18848+01	.19299+01	.52429+00
3	.28895+01	.40201+01	.44581+00
4	.41077+01	.70513+01	.36164+00
5	.51963+01	.10383+02	.29944+00
6	.63710+01	.14613+02	.25932+00
7	.72499+01	.18153+02	.23874+00
8	.82311+01	.22422+02	.22169+00

WALL COORDINATES

R/R*	X/R*	SLOPE(DEG)
1.0002026	.0232117	
1.0003413	.0301277	1.14903
1.0005160	.0370430	1.44705
1.0007266	.0439572	1.74498
1.0009732	.0508702	2.04297
1.0012558	.0577819	2.34101
1.0015743	.0646920	2.63911
1.0019287	.0716003	2.93691
1.0023191	.0785067	3.23504
1.0027453	.0854110	3.53301
1.0032075	.0923130	3.83096
1.0037056	.0992125	4.12913
1.0042395	.1061092	4.42679
1.0048093	.1130032	4.72507
1.0054150	.1198940	5.02298
1.0060565	.1267817	5.32103
1.0067338	.1336658	5.61910
1.0074469	.1405464	5.91682
1.0081958	.1474232	6.21508
1.0089804	.1542960	6.51301
1.0098008	.1611646	6.81099
1.0106569	.1680288	7.10903
1.0115486	.1748885	7.40702
1.0124761	.1817435	7.70484
1.0134391	.1885936	8.00311
1.0144378	.1954385	8.30098
1.0154721	.2022782	8.59907
1.0165420	.2091124	8.89690
1.0176473	.2159410	9.19510
1.0187882	.2227637	9.49293
1.0199645	.2295803	9.79101
1.0211763	.2363908	10.08898
1.0224235	.2431949	10.38698
1.0237061	.2499924	10.68501

1.0250240	.2567831	10.98296
1.0263772	.2635669	11.28121
1.0277656	.2703435	11.57889
1.0291893	.2771129	11.87701
1.0306482	.2838747	12.17508
1.0321422	.2906289	12.47298
1.0336713	.2973752	12.77084
1.0352355	.3041134	13.06905
1.0368348	.3108434	13.36711
1.0384650	.3175651	13.66492
1.0401381	.3242781	13.96296
1.0418421	.3309824	14.26101
1.0435810	.3376777	14.55897
1.0453547	.3443638	14.85704
1.0471631	.3510407	15.15503
1.0490063	.3577080	15.45292
1.0508841	.3643657	15.75111
1.0527964	.3710136	16.04899
1.0547434	.3776513	16.34690
1.0567248	.3842789	16.64503
1.0587407	.3908961	16.94308
1.0607910	.3975027	17.24099
1.0628756	.4040985	17.53897
1.0649944	.4106835	17.83708
1.0671475	.4172573	18.13488
1.0693348	.4238198	18.43305
1.0715562	.4303709	18.73100
1.0738115	.4369103	19.02893
1.0761009	.4434379	19.32711
1.0784242	.4499535	19.62483
1.0807814	.4564569	19.92319
1.0831724	.4629480	20.22097
1.0855970	.4694265	20.51892
1.0880554	.4758924	20.81703
1.0905473	.4823454	21.11485
1.0930728	.4887853	21.41306
1.0956317	.4952120	21.71100
1.0982240	.5016254	22.00903
1.1008497	.5080251	22.30701
1.1035086	.5144111	22.60498
1.1062007	.5207832	22.90302
1.1089258	.5271412	23.20095
1.1116840	.5334850	23.49898
1.1144752	.5398143	23.79702
1.1172992	.5461290	24.09506
1.1201561	.5524289	24.39287
1.1230457	.5587139	24.69109
1.1259679	.5649838	24.98896
1.1289227	.5712384	25.28709
1.1319100	.5774775	25.58484
1.1349297	.5837010	25.88305
1.1379817	.5899088	26.18099
1.1410660	.5961006	26.47900
1.1441824	.6022762	26.77698
1.1473309	.6084356	27.07496
1.1505114	.6145785	27.37302
1.1537238	.6207047	27.67096

1.1569681	.6268142	27.96904
1.1602440	.6329067	28.26699
1.1635516	.6389821	28.56493
1.1668908	.6450403	28.86309
1.1702614	.6510809	29.16093
1.1736634	.6571040	29.45900
1.1770967	.6631093	29.75696
1.1805611	.6690966	30.05508
1.1840567	.6750659	30.35307
1.1875833	.6810170	30.65085
1.2005278	.7027581	30.76936
1.2139594	.7253731	30.70702
1.2278743	.7488622	30.64244
1.2422687	.7732252	30.57571
1.2571384	.7984623	30.50677
1.2724797	.8245734	30.43577
1.2882881	.8515585	30.36265
1.3045594	.8794176	30.28745
1.3212894	.9081508	30.21026
1.3384735	.9377579	30.13108
1.3561073	.9682390	30.04997
1.3741861	.9995942	29.96695
1.3927053	1.0318234	29.88207
1.4116601	1.0649266	29.79538
1.4310458	1.0989038	29.70695
1.4508575	1.1337550	29.61677
1.4710904	1.1694802	29.52493
1.4917395	1.2060794	29.43147
1.5127999	1.2435527	29.33646
1.5342665	1.2818999	29.23992
1.5561344	1.3211212	29.14193
1.5783985	1.3612164	29.04256
1.6010538	1.4021857	28.94184
1.6240953	1.4440290	28.83986
1.6475179	1.4867463	28.73666
1.6713166	1.5303376	28.63234
1.6954864	1.5748030	28.52694
1.7200223	1.6201423	28.42053
1.7449193	1.6663557	28.31318
1.7701726	1.7134430	28.20501
1.7957774	1.7614044	28.09604
1.8217287	1.8102398	27.98638
1.8480219	1.8599492	27.87609
1.8746524	1.9105326	27.76527
1.9016154	1.9619900	27.65397
1.9289061	2.0143214	27.54195
1.9565193	2.0675268	27.42895
1.9844498	2.1216063	27.31507
2.0126925	2.1765597	27.20031
2.0412421	2.2323872	27.08480
2.0700938	2.2890887	26.96853
2.0992424	2.3466642	26.85162
2.1286830	2.4051137	26.73408
2.1584107	2.4644372	26.61600
2.1884207	2.5246347	26.49741
2.2187082	2.5857063	26.37846
2.2492687	2.6476519	26.25910

2.2800974	2.7104714	26.13952
2.3111899	2.7741650	26.01970
2.3425419	2.8387326	25.89975
2.3741491	2.9041741	25.77976
2.4060073	2.9704897	25.65975
2.4381125	3.0376793	25.53987
2.4704608	3.1057430	25.42012
2.5030484	3.1746806	25.30064
2.5358718	3.2444922	25.18153
2.5689274	3.3151779	25.06278
2.6022119	3.3867376	24.94455
2.6357223	3.4591712	24.82693
2.6694555	3.5324789	24.70996
2.7034088	3.6066606	24.59377
2.7375796	3.6817164	24.47847
2.7719655	3.7576461	24.36407
2.8065642	3.8344498	24.25073
2.8413739	3.9121276	24.13857
2.8763928	3.9906793	24.02763
2.9116192	4.0701051	23.91790
2.9470492	4.1504048	23.80815
2.9826775	4.2315786	23.69733
3.0184985	4.3136263	23.58548
3.0545067	4.3965482	23.47257
3.0906966	4.4803439	23.35864
3.1270626	4.5650138	23.24369
3.1635990	4.6505576	23.12770
3.2003003	4.7369754	23.01071
3.2371607	4.8242673	22.89271
3.2741747	4.9124331	22.77372
3.3113364	5.0014730	22.65374
3.3486403	5.0913869	22.53279
3.3860805	5.1821748	22.41085
3.4236513	5.2738367	22.28796
3.4613469	5.3663726	22.16413
3.4991616	5.4597825	22.03934
3.5370896	5.5540665	21.91363
3.5751249	5.6492244	21.78699
3.6132620	5.7452564	21.65943
3.6514948	5.8421623	21.53098
3.6898176	5.9399423	21.40165
3.7282245	6.0385963	21.27141
3.7667096	6.1381243	21.14031
3.8052671	6.2385263	21.00836
3.8438912	6.3398023	20.87556
3.8825759	6.4419523	20.74193
3.9213154	6.5449764	20.60746
3.9601039	6.6488745	20.47220
3.9989353	6.7536466	20.33612
4.0378040	6.8592926	20.19927
4.0767040	6.9658127	20.06164
4.1156294	7.0732068	19.92324
4.1545755	7.1814749	19.78462
4.1935400	7.2906170	19.64695
4.2325212	7.4006331	19.51039
4.2715176	7.5115232	19.37506
4.3105276	7.6232874	19.24098

4.3495503	7.7359256	19.10827
4.3885846	7.8494377	18.97695
4.4276299	7.9638239	18.84715
4.4666858	8.0790840	18.71892
4.5057518	8.1952162	13.59229
4.5448282	8.3122264	18.46737
4.5839150	8.4301027	18.34423
4.6230128	6.5488648	18.22296
4.6621222	8.6684951	18.10358
4.7012445	8.7889993	17.98624
4.7403807	8.9103775	17.87099
4.7795324	9.0326297	17.75786
4.8187015	9.1557560	17.64697
4.8578900	9.2797563	17.53839
4.8971003	9.4046305	17.43221
4.9363351	9.5303788	17.32848
4.9755975	9.6570011	17.22733
5.0148906	9.7844975	17.12878
5.0542181	9.9128678	17.03296
5.0935839	10.0421121	16.93990
5.1329922	10.1722305	16.84973
5.1724476	10.3032229	16.76250
5.2119550	10.4350892	16.67829
5.2515166	10.5678296	16.59606
5.2911314	10.7014440	16.51433
5.3307978	10.8359324	16.43306
5.3705146	10.9712948	16.35228
5.4102808	11.1075312	16.27203
5.4500949	11.2446417	16.19225
5.4899561	11.3826261	16.11303
5.5298634	11.5214845	16.03441
5.5698159	11.6612170	15.95637
5.6098129	11.8018235	15.87895
5.6498535	11.9433059	15.80215
5.6899374	12.0856584	15.72605
5.7300640	12.2288870	15.65062
5.7702328	12.3729895	15.57590
5.8104456	12.5179660	15.50192
5.8506961	12.6638166	15.42871
5.8909904	12.8105412	15.35627
5.9313263	12.9581398	15.28466
5.9717041	13.1066123	15.21391
6.0121239	13.2559589	15.14396
6.0525861	13.4061795	15.07495
6.0930911	13.5572741	15.00684
6.1336395	13.7092427	14.93966
6.1742319	13.8620853	14.87346
6.2148693	14.0158020	14.80825
6.2555525	14.1703926	14.74405
6.2962825	14.3258573	14.68090
6.3370605	14.4821960	14.61881
6.3778878	14.6394087	14.55784
6.4187654	14.7974954	14.49784
6.4596939	14.9564561	14.43849
6.5006719	15.1162908	14.37979
6.5417011	15.2769996	14.32176
6.5827810	15.4395823	14.26435

6.6239120	15.6010391	14.20767
6.6650944	15.7643698	14.15166
6.7063239	15.92[illegible]746	14.09641
6.7476158	16.0936532	14.04187
6.7889558	16.2596059	13.98810
6.8303497	16.4264326	13.93509
6.8717983	16.5941334	13.88289
6.9133025	16.7627082	13.83149
6.9548634	16.9321570	13.78095
6.9964820	17.1024799	13.73122
7.0381594	17.2736766	13.68238
7.0798972	17.4457474	13.63442
7.1216966	17.6186922	13.58738
7.1635592	17.7925110	13.54126
7.2054866	17.9672039	13.49608
7.2474805	18.1427708	13.45186
7.2895424	18.3192117	13.40851
7.3316720	18.4965265	13.36552
7.3738686	18.6747153	13.32271
7.4161317	18.8537781	13.28013
7.4584606	19.0337150	13.23774
7.5008547	19.2145259	13.19558
7.5433134	19.3962109	13.15363
7.5858362	19.5787699	13.11192
7.6284227	19.7622030	13.07045
7.6710724	19.9465098	13.02923
7.7137847	20.1316907	12.98823
7.7565594	20.3177457	12.94751
7.7993960	20.5046747	12.90705
7.8422944	20.6924777	12.86687
7.8852542	20.8811548	12.82698
7.9282751	21.0707059	12.78734
7.9713570	21.2611308	12.74803
8.0144995	21.4524298	12.70897
8.0577028	21.6446028	12.67025
8.1009667	21.8376498	12.63188
8.1442910	22.0315709	12.59377
8.1876760	22.2263660	12.55602
8.2311260	22.4220562	12.51857
.0000000	.0000000	

PC= 800.00 PSIA XI= .30791 TAU= .10000+09 MILLI SEC.

MEAN PARTICLE DIAMETER(MICRONS)= 6.6206

PARTICLE SIZE DISTRIBUTION

GROUP	R(FT)	D(MICRONS)	WPWT
1	.2095-05	1.2772	.10000-01
2	.2923-05	1.7817	.20000-01
3	.3795-05	2.3135	.40000-01
4	.4959-05	3.0230	.80000-01
5	.6704-05	4.0568	.15000
6	.1392-04	8.4982	.70000

K BAR=1.1316289 WDG= 162.0994 EQUILIBRIUM CONDITIONS.

ONE DIMENSIONAL FLOW

Z0= -4.7322 ZMAX= -2.57877 DZ= .00200 U0= 348.038 TPI0= 6340.827 A0= 1.9717

```
 Z=  -2.5788     DZ=  .001424     A/AT=  1.78188     UG= 1237.414     TG= 6294.180
    UP(I)           TP(I)          K(I)            L(I)         I=1,... 6
   1224.174      6294.667        .98930          .99043      1214.678      6295.046        .98163        .98297
   1204.500      6295.514        .97340          .97377      1189.695      6296.207        .96144        .96012
   1166.128      6297.324        .94239          .93815      1071.419      6301.898        .86585        .84814
UUS=      .366933+00      USG=       .337232+04     ZSINK=      -.142549+01
K BAR=1.1320480        WDG CONST LAG =  165.4423
CD14,CD1,CD,DELT1,DELT            .99696      .97935      .99694          -.017611 -.018777         5

   WDG=     164.9365      WDP(I)=          .7548        1.5096        3.0191        6.0383      11.5217      52.8348

ONE DIMENSIONAL FLOW
Z0=  -4.7734     ZMAX= -2.57877     DZ= .00200     U0=  548.038     TPI0= 6540.827     A0=    2.0062

 Z=  -2.5788     DZ=  .000656     A/AT=  1.78188     UG= 1262.093     TG= 6292.081
    UP(I)           TP(I)          K(I)            L(I)         I=1,... 6
   1248.279      6292.670        .98906          .98888      1238.484      6293.073        .98129        .98126
   1227.931      6293.569        .97293          .97189      1212.600      6294.302        .96079        .95805
   1188.243      6295.480        .94149          .93577      1090.838      6300.283        .86431        .84501
UUS=      .366707+00      USG=       .344170+04     ZSINK=      -.142549+01
K BAR=1.1320648        WDG CONST LAG =  165.4658
CD14,CD1,CD,DELT1,DELT            .99696      .98280      .99617          -.014157 -.014157         2

   WDG=     164.8332      WDP(I)=          .7543        1.5086        3.0172        6.0345      11.3146      52.8017

PARTICLE LAG VALUES AT INTERCEPT POSITIONS ON THE MOC INITIAL LINE.

    J     I      K(U)          K(V)            L            R
    1     1       .98510        .92630        .98040       .52354
    1     2       .97572        .88308        .96800       .51773
    1     3       .96466        .83502        .95423       .51113
    1     4       .94807        .76687        .93464       .50199
    1     5       .92202        .66432        .90458       .48871
    1     6       .82886        .33555        .78640       .44666

    J     I      K(U)          K(V)            L            R
    2     1       .98300        .91673        .97610       .72869
    2     2       .97188        .86612        .96115       .72104
    2     3       .95920        .81171        .94619       .71242
    2     4       .93966        .73147        .92294       .70063
    2     5       .91066        .61692        .88846       .68350
    2     6       .81396        .28088        .76260       .62954

    J     I      K(U)          K(V)            L            R
    3     1       .97924        .90029        .97017       .88206
    3     2       .96581        .83980        .95326       .87353
    3     3       .94924        .76856        .93253       .86396
    3     4       .92584        .67278        .90245       .85096
    3     5       .89433        .54973        .86343       .83216
    3     6       .79554        .21870        .73304       .77287

    J     I      K(U)          K(V)            L            R
    4     1       .96452        .82754        .94409      1.00989
    4     2       .94666        .74666        .91913      1.00098
    4     3       .92791        .66549        .89437       .99102
    4     4       .90391        .56699        .86371       .97755
```

4	5	.87117	.44205	.82244	.95813
4	6	.77273	.13277	.69520	.89690

	P / H-PJ	RHO / RHO-PJ	U / U-PJ	V / V-PJ	R	Z	PT.NO.	MACH NO.
	.1143157+07	.8398594-01	.4856493+04	.9704411+03	.1025788+01	.2606119+00	0	1.23479
	.1142979+07	.8397689-01	.4856603+04	.9715211+03	.1024997+01	.2611122+00	1	1.23488
	.1142413+07	.8394066-01	.4856938+04	.9747305+03	.1022626+01	.2626122+00	2	1.23516
	.1144168+07	.8405455-01	.4853596+04	.9760596+03	.1018677+01	.2651097+00	3	1.23430
	.1151697+07	.8454297-01	.4840973+04	.9733471+03	.1009889+01	.2706694+00	4	1.23061
J= 1	.628015+08	.451818-03	.466919+04	.805481+03				
	.1159207+07	.8502979-01	.4828502+04	.9702517+03	.1000978+01	.2763060+00	5	1.22694
J= 1	.627855+08	.452102-03	.466212+04	.807840+03				
J= 2	.630195+08	.940122-03	.457095+04	.724447+03				
	.1167454+07	.8556389-01	.4814948+04	.9663965+03	.9910209+00	.2826048+00	6	1.22294
J= 1	.627679+08	.452414-03	.465456+04	.810106+03				
J= 2	.629962+08	.940592-03	.456533+04	.728602+03				
J= 3	.632356+08	.196361-02	.446782+04	.643128+03				
	.1178362+07	.8626970-01	.4797242+04	.9605463+03	.9775521+00	.2911250+00	7	1.21767
J= 1	.627439+08	.452828-03	.464489+04	.812565+03				
J= 2	.629647+08	.941212-03	.455825+04	.733647+03				
J= 3	.632005+08	.196452-02	.446224+04	.649729+03				
J= 4	.635033+08	.415659-02	.433629+04	.544621+03				
	.1193594+07	.8725407-01	.4772948+04	.9508983+03	.9581279+00	.3034124+00	8	1.21056
J= 1	.627093+08	.453406-03	.463205+04	.814916+03				
J= 2	.629192+08	.942077-03	.454910+04	.739777+03				
J= 3	.631498+08	.196578-02	.445521+04	.658186+03				
J= 4	.634514+08	.416064-02	.433039+04	.554586+03				
J= 5	.638637+08	.845355-02	.415803+04	.420348+03				
	.1195966+07	.8740722-01	.4769211+04	.9492361+03	.9550357+00	.3053698+00	9	1.20923
J= 1	.627037+08	.453496-03	.463012+04	.815163+03				
J= 2	.629120+08	.942211-03	.454775+04	.740630+03				
J= 3	.631417+08	.196597-02	.445420+04	.659418+03				
J= 4	.634432+08	.416126-02	.432955+04	.556071+03				
J= 5	.638549+08	.845519-02	.415749+04	.422124+03				
	.1209068+07	.8825249-01	.4748792+04	.9392502+03	.9375780+00	.3164120+00	10	1.20300
J= 1	.626726+08	.453995-03	.461985+04	.815918+03				
J= 2	.628712+08	.942953-03	.454074+04	.744827+03				
J= 3	.630962+08	.196704-02	.444905+04	.665783+03				
J= 4	.633965+08	.416469-02	.432557+04	.563922+03				
J= 5	.638053+08	.846424-02	.415493+04	.431698+03				
	.1222878+07	.8914236-01	.4727684+04	.9271868+03	.9184472+00	.3285138+00	11	1.19648
J= 1	.626385+08	.454522-03	.460973+04	.815534+03				
J= 2	.628264+08	.943734-03	.453414+04	.748219+03				
J= 3	.630463+08	.196815-02	.444446+04	.671619+03				
J= 4	.633454+08	.416826-02	.432181+04	.571502+03				
J= 5	.637510+08	.847366-02	.415510+04	.441316+03				
	.1237743+07	.9009587-01	.4705451+04	.9123195+03	.8969035+00	.3421420+00	12	1.18952
J= 1	.626002+08	.455091-03	.459973+04	.813643+03				
J= 2	.627760+08	.944571-03	.452805+04	.750587+03				
J= 3	.629901+08	.196933-02	.444058+04	.676793+03				
J= 4	.632878+08	.417203-02	.431904+04	.578762+03				
J= 5	.636898+08	.848364-02	.415221+04	.451041+03				
J= 6	.649747+08	.507331-01	.363612+04	.121129+03				
	.1251881+07	.9100734-01	.4684788+04	.8962160+03	.8753568+00	.3557721+00	13	1.18294
J= 1	.625715+08	.455634-03	.458852+04	.807497+03				
J= 2	.627256+08	.945365-03	.452334+04	.751453+03				
J= 3	.629339+08	.197044-02	.443803+04	.680513+03				
J= 4	.632302+08	.417554-02	.431756+04	.584684+03				
J= 5	.636286+08	.849295-02	.415254+04	.459588+03				

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J= 6	.649173+08	.509764-01	.363870+04	.132366+03				
	.1266678+07	.9195687-01	.4663685+04	.8771065+03	.8515064+00	.5708595+00	14	1.17611
J= 1	.625634+08	.456204-03	.457037+04	.792520+03				
J= 2	.627114+08	.946194-03	.450832+04	.739931+03				
J= 3	.628942+08	.197158-02	.443078+04	.677220+03				
J= 4	.631665+08	.417913-02	.431738+04	.589697+03				
J= 5	.635608+08	.850249-02	.415428+04	.467669+03				
J= 6	.648538+08	.512321-01	.364275+04	.144037+03				
	.1281397+07	.9290014-01	.4643248+04	.8555139+03	.8261990+00	.5868686+00	15	1.16936
J= 1	.625549+08	.456775-03	.455321+04	.775330+03				
J= 2	.627000+08	.947015-03	.449524+04	.725451+03				
J= 3	.628740+08	.197268-02	.441909+04	.666713+03				
J= 4	.631356+08	.418259-02	.430947+04	.583841+03				
J= 5	.634971+08	.851172-02	.415564+04	.472609+03				
J= 6	.647864+08	.514679-01	.364838+04	.155491+03				
	.1295829+07	.9382377-01	.4623787+04	.8314524+03	.7994994+00	.4037583+00	16	1.16279
J= 1	.625459+08	.457338-03	.453715+04	.755903+03				
J= 2	.626880+08	.947815-03	.447932+04	.708878+03				
J= 3	.628526+08	.197374-02	.440868+04	.654282+03				
J= 4	.63[illegible]38+08	.418585-02	.430276+04	.576087+03				
J= 5	.634578+08	.852046-02	.415179+04	.469350+03				
J= 6	.647152+08	.517405-01	.365577+04	.166498+03				
	.1309764+07	.9471446-01	.4605588+04	.8049817+03	.7714769+00	.4214849+00	17	1.15649
J= 1	.625364+08	.457886-03	.452245+04	.734255+03				
J= 2	.626753+08	.948584-03	.446682+04	.690202+03				
J= 3	.628303+08	.197472-02	.439982+04	.639874+03				
J= 4	.630705+08	.418885-02	.429769+04	.566552+03				
J= 5	.634166+08	.852853-02	.414963+04	.464603+03				
J= 6	.646418+08	.519864-01	.366475+04	.176535+03				
	.1322995+07	.9555917-01	.4588917+04	.7762054+03	.7422045+00	.4400022+00	18	1.15055
J= 1	.625265+08	.458412-03	.450937+04	.710444+03				
J= 2	.626621+08	.949308-03	.445599+04	.669451+03				
J= 3	.628069+08	.197562-02	.439272+04	.623470+03				
J= 4	.630356+08	.419151-02	.429449+04	.555170+03				
J= 5	.633736+08	.853577-02	.414936+04	.458265+03				
J= 6	.645891+08	.522224-01	.366875+04	.180082+03				
	.1335323+07	.9634531-01	.4574012+04	.7452731+03	.7117594+00	.4592613+00	19	1.14504
J= 1	.625189+08	.458907-03	.449703+04	.683800+03				
J= 2	.626498+08	.949976-03	.444617+04	.646071+03				
J= 3	.627829+08	.197640-02	.438749+04	.605000+03				
J= 4	.629994+08	.419378-02	.429334+04	.541503+03				
J= 5	.633288+08	.854199-02	.415119+04	.450257+03				
J= 6	.645343+08	.524451-01	.367473+04	.182748+03				
	.1346558+07	.9706103-01	.4561085+04	.7123647+03	.6802225+00	.4792110+00	20	1.14005
J= 1	.625131+08	.459366-03	.448579+04	.654655+03				
J= 2	.626405+08	.950576-03	.443633+04	.619417+03				
J= 3	.627719+08	.197705-02	.437899+04	.580888+03				
J= 4	.629757+08	.419559-02	.428982+04	.525661+03				
J= 5	.632849+08	.854704-02	.415449+04	.440042+03				
J= 6	.644775+08	.526515-01	.368284+04	.184425+03				
	.1356525+07	.9769533-01	.4550320+04	.6776949+03	.6476789+00	.4997976+00	21	1.13564
J= 1	.623072+08	.459780-03	.447673+04	.623823+03				
J= 2	.626309+08	.951098-03	.442866+04	.591111+03				
J= 3	.627605+08	.197755-02	.437267+04	.555171+03				
J= 4	.629589+08	.419686-02	.428597+04	.502106+03				
J= 5	.632614+08	.855076-02	.415331+04	.423992+03				
J= 6	.644189+08	.528383-01	.369318+04	.185017+03				

	.1365063+07	.9823930-01	.4541871+04	.6415009+03	.6142176+00	.5209647+00	22	1.13188
J= 1	.625010+08	.460145-03	.446997+04	.591509+03				
J= 2	.626211+08	.951531-03	.442331+04	.561332+03				
J= 3	.627489+08	.197789-02	.436867+04	.528006+03				
J= 4	.629417+08	.419757-02	.428444+04	.479115+03				
J= 5	.632372+08	.855300-02	.415446+04	.406570+03				
J= 6	.643688+08	.530029-01	.370258+04	.183123+03				
	.1372034+07	.9868134-01	.4535863+04	.6040373+03	.5799317+00	.5426534+00	23	1.12882
J= 1	.624948+08	.460453-03	.446566+04	.557932+03				
J= 2	.626110+08	.951866-03	.442040+04	.530277+03				
J= 3	.627369+08	.197804-02	.436710+04	.499569+03				
J= 4	.629241+08	.419764-02	.428536+04	.454826+03				
J= 5	.632124+08	.855363-02	.415803+04	.387865+03				
J= 6	.643298+08	.531426-01	.371036+04	.178620+03				
	.1377323+07	.9901729-01	.4532392+04	.5655677+03	.5449183+00	.5648023+00	24	1.12650
J= 1	.624883+08	.460700-03	.446387+04	.523323+03				
J= 2	.626007+08	.952094-03	.442002+04	.498157+03				
J= 3	.627247+08	.197801-02	.436806+04	.470046+03				
J= 4	.629061+08	.419704-02	.428880+04	.429388+03				
J= 5	.631871+08	.855254-02	.416410+04	.367981+03				
J= 6	.642900+08	.532549-01	.372044+04	.173165+03				
	.1380839+07	.9924054-01	.4531522+04	.5263589+03	.5092790+00	.5873472+00	25	1.12496
J= 1	.624840+08	.460881-03	.446414+04	.474287+03				
J= 2	.625922+08	.952208-03	.442165+04	.457229+03				
J= 3	.627128+08	.197777-02	.437141+04	.437929+03				
J= 4	.628878+08	.419573-02	.429482+04	.402963+03				
J= 5	.631613+08	.854962-02	.417272+04	.347034+03				
J= 6	.642495+08	.533378-01	.373289+04	.166760+03				
	.1382519+07	.9934719-01	.4533289+04	.4866737+03	.4731198+00	.6102210+00	26	1.12423
J= 1	.624828+08	.460992-03	.446621+04	.407392+03				
J= 2	.625901+08	.952203-03	.442397+04	.392740+03				
J= 3	.627099+08	.197732-02	.437494+04	.376162+03				
J= 4	.628809+08	.419367-02	.429915+04	.351749+03				
J= 5	.631440+08	.854481-02	.418087+04	.312594+03				
J= 6	.642084+08	.533896-01	.374770+04	.159456+03				
	.1382329+07	.9933513-01	.4537697+04	.4467652+03	.4365518+00	.6333533+00	27	1.12451
J= 1	.624815+08	.461030-03	.447088+04	.345079+03				
J= 2	.625879+08	.952072-03	.442888+04	.332668+03				
J= 3	.627071+08	.197664-02	.437923+04	.318626+03				
J= 4	.628769+08	.419086-02	.430492+04	.297947+03				
J= 5	.631383+08	.853804-02	.418750+04	.265120+03				
J= 6	.641749+08	.534087-01	.376238+04	.146521+03				
	.1380264+07	.9920401-01	.4544721+04	.4068718+03	.3996917+00	.6566704+00	28	1.12522
J= 1	.624803+08	.460992-03	.447813+04	.287730+03				
J= 2	.625857+08	.951814-03	.443655+04	.277382+03				
J= 3	.627042+08	.197574-02	.438695+04	.265674+03				
J= 4	.628729+08	.418727-02	.431519+04	.248432+03				
J= 5	.631325+08	.852927-02	.419658+04	.221060+03				
J= 6	.641621+08	.533942-01	.377281+04	.122171+03				
	.1376347+07	.9895520-01	.4554305+04	.3672130+03	.3626623+00	.6800946+00	29	1.12693
J= 1	.624791+08	.460877-03	.448791+04	.235626+03				
J= 2	.625835+08	.951426-03	.444652+04	.227152+03				
J= 3	.627013+08	.197462-02	.439715+04	.217564+03				
J= 4	.628689+08	.418290-02	.432590+04	.203444+03				
J= 5	.631267+08	.851651-02	.420803+04	.181029+03				
J= 6	.641492+08	.533454-01	.378540+04	.108047+03				
	.1370631+07	.9859222-01	.4566362+04	.3279871+03	.3255941+00	.7035434+00	30	1.12943

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J= 1	.624778+08	.460685-03	.450013+04	.188945+03				
J= 2	.625813+08	.950909-03	.445871+04	.182150+03				
J= 3	.626984+08	.197327-02	.440974+04	.174462+03				
J= 4	.628648+08	.417776-02	.433697+04	.163139+03				
J= 5	.631209+08	.850577-02	.422179+04	.145164+03				
J= 6	.641363+08	.532624-01	.380007+04	.802266+02				
	.1363200+07	.9811984-01	.4580776+04	.2893696+03	.2886268+00	.7269284+00	31	1.13270
J= 1	.624766+08	.460417-03	.451468+04	.147772+03				
J= 2	.625791+08	.950265-03	.447340+04	.142457+03				
J= 3	.626955+08	.197171-02	.442461+04	.136444+03				
J= 4	.628608+08	.417187-02	.435229+04	.127589+03				
J= 5	.631151+08	.849110-02	.423773+04	.113532+03				
J= 6	.641235+08	.531454-01	.381671+04	.627443+02				
	.1354161+07	.9754493-01	.4597394+04	.2515144+03	.2519114+00	.7501539+00	32	1.13668
J= 1	.624754+08	.460074-03	.453139+04	.112102+03				
J= 2	.625769+08	.949499-03	.449025+04	.108070+03				
J= 3	.626926+08	.196994-02	.444161+04	.103509+03				
J= 4	.628568+08	.416527-02	.436970+04	.967910+02				
J= 5	.631094+08	.847460-02	.425572+04	.861267+02				
J= 6	.641108+08	.529954-01	.383520+04	.475988+02				
	.1343654+07	.9687507-01	.4616031+04	.2145576+03	.2156147+00	.7731146+00	33	1.14134
J= 1	.624742+08	.459662-03	.455010+04	.818513+02				
J= 2	.625748+08	.948617-03	.450906+04	.789075+02				
J= 3	.626898+08	.196797-02	.446055+04	.755769+02				
J= 4	.628529+08	.415801-02	.438902+04	.706719+02				
J= 5	.631037+08	.845639-02	.427556+04	.628853+02				
J= 6	.640982+08	.528141-01	.385534+04	.347542+02				
	.1331848+07	.9612377-01	.4636457+04	.1786245+03	.1799249+00	.7956915+00	34	1.14659
J= 1	.624730+08	.459164-03	.457056+04	.568637+02				
J= 2	.625727+08	.947630-03	.452962+04	.548186+02				
J= 3	.626870+08	.196583-02	.448122+04	.525048+02				
J= 4	.628490+08	.415016-02	.441002+04	.490972+02				
J= 5	.630981+08	.843664-02	.429704+04	.436877+02				
J= 6	.640858+08	.526037-01	.387695+04	.241445+02				
	.1318946+07	.9530077-01	.4658392+04	.1438434+03	.1450614+00	.8177456+00	35	1.15236
J= 1	.624718+08	.458649-03	.459251+04	.369186+02				
J= 2	.625706+08	.946550-03	.455165+04	.355908+02				
J= 3	.626842+08	.196353-02	.450334+04	.340885+02				
J= 4	.628452+08	.414180-02	.443244+04	.318762+02				
J= 5	.630926+08	.841559-02	.431987+04	.283641+02				
J= 6	.640737+08	.523675-01	.389975+04	.156757+02				
	.1305196+07	.9442265-01	.4681484+04	.1103695+03	.1112930+00	.8391069+00	36	1.15855
J= 1	.624707+08	.458065-03	.461559+04	.217330+02				
J= 2	.625686+08	.945395-03	.457479+04	.209514+02				
J= 3	.626816+08	.196113-02	.452655+04	.200670+02				
J= 4	.628416+08	.413306-02	.445593+04	.187647+02				
J= 5	.630874+08	.839354-02	.434373+04	.166972+02				
J= 6	.640620+08	.521098-01	.392343+04	.922789+01				
	.1290912+07	.9350921-01	.4705274+04	.7842957+02	.7897350-01	.8595519+00	37	1.16503
J= 1	.624696+08	.457447-03	.463935+04	.109588+02				
J= 2	.625667+08	.944190-03	.459859+04	.105647+02				
J= 3	.626790+08	.195865-02	.455041+04	.101187+02				
J= 4	.628381+08	.412410-02	.448003+04	.946203+01				
J= 5	.630823+08	.837091-02	.436816+04	.841951+01				
J= 6	.640508+08	.518365-01	.394754+04	.465313+01				
	.1276517+07	.9258758-01	.4729113+04	.4841797+02	.4862291-01	.8787510+00	38	1.17159
J= 1	.624686+08	.456813-03	.466314+04	.416539+01				

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07/26/82  09:49:57 MA     0425AA410    MA           10    300                                           DATE 072682       PAGE   17
        J= 2     .625649+08     .942969-05     .462242+04     .401555+01
        J= 3     .626767+08     .195617-02     .457427+04     .384604+01
        J= 4     .628348+08     .411516-02     .450411+04     .359643+01
        J= 5     .630775+08     .834430-02     .439251+04     .320018+01
        J= 6     .640402+08     .515561-01     .397148+04     .176861+01
      .1262703+07       .9170190-01       .4751915+04      .2117251+02       .2118395-01       .5961085+00      39   1.17794
        J= 1     .624677+08     .456195-05     .468588+04     .793565+00
        J= 2     .625633+08     .941791-05     .464518+04     .765024+00
        J= 3     .626745+08     .195380-02     .459705+04     .732733+00
        J= 4     .628318+08     .410663-02     .452708+04     .685178+00
        J= 5     .630732+08     .832672-02     .441570+04     .609686+00
        J= 6     .640307+08     .512828-01     .399421+04     .336949+00
      .1251523+07       .9098437-01       .4770332+04      .0000000          .0000000          .9095491+00      40   1.18311
        J= 1     .624670+08     .455690-05     .470425+04     .000000
        J= 2     .625620+08     .940834-05     .466355+04     .000009
        J= 3     .626724+08     .195189-02     .461544+04     .000000
        J= 4     .628295+08     .409976-02     .454559+04     .000000
        J= 5     .630699+08     .850932-02     .443458+04     .000000
        J= 6     .640233+08     .510590-01     .401247+04     .000000

INTEGRATED PARTICLE WEIGHT FLOW RATES...
PT.NO.= 39      WDP(I)=     .000     .001     .001     .003     .005     .030
PT.NO.= 38      WDP(I)=     .002     .003     .007     .014     .029     .159
PT.NO.= 37      WDP(I)=     .004     .009     .018     .038     .075     .420
PT.NO.= 36      WDP(I)=     .009     .018     .036     .075     .149     .834
PT.NO.= 35      WDP(I)=     .015     .030     .062     .128     .253    1.416
PT.NO.= 34      WDP(I)=     .023     .046     .095     .196     .359    2.178
PT.NO.= 33      WDP(I)=     .032     .066     .136     .282     .558    3.128
PT.NO.= 32      WDP(I)=     .044     .090     .185     .385     .762    4.270
PT.NO.= 31      WDP(I)=     .058     .119     .243     .505    1.000    5.606
PT.NO.= 30      WDP(I)=     .074     .151     .310     .644    1.274    7.136
PT.NO.= 29      WDP(I)=     .092     .188     .385     .799    1.592    8.857
PT.NO.= 28      WDP(I)=     .112     .228     .468     .973    1.924   10.762
PT.NO.= 27      WDP(I)=     .133     .273     .559    1.163    2.300   12.846
PT.NO.= 26      WDP(I)=     .157     .321     .659    1.369    2.707   15.094
PT.NO.= 25      WDP(I)=     .183     .373     .766    1.591    3.145   17.489
PY.NO.= 24      WDP(I)=     .210     .429     .879    1.827    3.609   20.012
PT.NO.= 23      WDP(I)=     .239     .487     .999    2.075    4.096   22.646
PT.NO.= 22      WDP(I)=     .268     .548    1.124    2.334    4.603   25.374
PT.NO.= 21      WDP(I)=     .299     .612    1.253    2.602    5.127   28.175
PT.NC.= 20      WDP(I)=     .331     .677    1.386    2.877    5.665   31.025
PT.NO.= 19      WDP(I)=     .364     .743    1.522    3.157    6.211   33.902
PT.NO.= 18      WDP(I)=     .397     .810    1.659    3.440    6.762   36.784
PT.NO.= 17      WDP(I)=     .430     .878    1.797    3.723    7.314   39.652
PT.NO.= 16      WDP(I)=     .463     .945    1.935    4.006    7.863   42.479
PT.NO.= 15      WDP(I)=     .496    1.012    2.071    4.285    8.403   45.243
PT.NO.= 14      WDP(I)=     .528    1.078    2.204    4.558    8.932   47.923
PT.NO.= 13      WDP(I)=     .560    1.141    2.334    4.823    9.443   50.502
PT.NO.= 12      WDP(I)=     .589    1.201    2.454    5.069    9.916   52.874
PT.NO.= 11      WDP(I)=     .619    1.261    2.577    5.320   10.399
PT.NO.= 10      WDP(I)=     .646    1.317    2.689    5.547   10.857
PT.NO.=  9      WDP(I)=     .671    1.368    2.793    5.759   11.244
PT.NO.=  8      WDP(I)=     .676    1.377    2.812    5.797   11.316
PT.NO.=  7      WDP(I)=     .705    1.435    2.930    6.037
PT.NO.=  6      WDP(I)=     .725    1.477    3.013
PT.NO.=  5      WDP(I)=     .740    1.507
PT.NO.=  4      WDP(I)=     .754
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1-- ENERGY FLOW RATE FOR PARTICLE  1 =   2199.8        2-- ENERGY FLOW RATE FOR PARTICLE  2 =   4389.1
3-- ENERGY FLOW RATE FOR PARTICLE  3 =   8751.7        4-- ENERGY FLOW RATE FOR PARTICLE  4 =   17474.
5-- ENERGY FLOW RATE FOR PARTICLE  5 =   32605.        6-- ENERGY FLOW RATE FOR PARTICLE  6 =   .15068+06
            ENERGY FLOW RATE FOR GAS =   .66336+06
               TOTAL ENERGY FLOW RATE =  .87946+06

**** NOZZLE WEIGHT FLOW, WDOT=   240.25    LB/SEC

**** NOZZLE DISCHARGE COEFFICIENT, CD=      1.01681
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                                                         GAS-PARTICLE FLOW
CHARACTERISTIC CALCULATION

LRC ID    R          Z        MACH      TG       VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP   IT
      K       REK             VPK              THETA-K          TPK     DPK/DG          DPK/DPO           RPK

 0 15  1.02579    .26061   1.2348   5531.4   4952.5   11.300  .87178  .30842  .35379  .00000  1.2371  194.92  0

LRC ID    R          Z        MACH      TG       VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP   IT
      K       REK             VPK              THETA-K          TPK     DPK/DG          DPK/DPO           RPK

 1  1  1.02500    .26111   1.2349   5531.3   4952.8   11.312  .87176  .30837  .35374  .00000   .0000     .00  0
 1  5  1.02598    .26156   1.2342   5532.1   4950.4   11.281  .87188  .30866  .35402  .00000  1.2372  194.94  2

IP= 3                      MASS FLOW RATE OF GAS=    .24482
                           TOTAL MASS FLOW RATE =    .24482

                       ENERGY FLOW RATE FOR GAS =    984.70
                         TOTAL ENERGY FLOW RATE =    984.70

LRC ID    R          Z        MACH      TG       VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP   IT
      K       REK             VPK              THETA-K          TPK     DPK/DG          DPK/DPO           RPK

 2  1  1.02263    .26261   1.2352   5531.0   4953.8   11.348  .87171  .30822  .35358  .00000   .0000     .00  0
 2  5  1.02655    .26442   1.2444   5520.9   4986.4   11.579  .87012  .30465  .35010  .00000  1.2376  195.00  2

IP= 4                      MASS FLOW RATE OF GAS=    .97704
                           TOTAL MASS FLOW RATE =    .97704

                       ENERGY FLOW RATE FOR GAS =    3929.8
                         TOTAL ENERGY FLOW RATE =    3929.8

LRC ID    R          Z        MACH      TG       VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP   IT
      K       REK             VPK              THETA-K          TPK     DPK/DG          DPK/DPO           RPK

 3  1  1.01868    .26511   1.2343   5532.0   4950.8   11.371  .87187  .30870  .35406  .00000   .0000     .00  0
 3  5  1.02753    .26920   1.2441   5521.2   4985.3   11.579  .87017  .30475  .35022  .00000  1.2382  195.09  2

IP= 4                      MASS FLOW RATE OF GAS=    2.1927
                           TOTAL MASS FLOW RATE =    2.1927

                       ENERGY FLOW RATE FOR GAS =    8819.6
                         TOTAL ENERGY FLOW RATE =    8819.6

LRC ID    R          Z        MACH      TG       VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP   IT
      K       REK             VPK              THETA-K          TPK     DPK/DG          DPK/DPO           RPK

 4 14  1.00989    .27067   1.2306   5536.2   4937.9   11.369  .87253  .31075  .35612  .00000   .0000     .00  0
 4  5  1.02978    .27987   1.2628   5500.7   5050.8   12.175  .86693  .29745  .34311  .00000  1.2396  195.31  2

IP= 4                      MASS FLOW RATE OF GAS=    4.8973
                           TOTAL MASS FLOW RATE =    4.8973

                       ENERGY FLOW RATE FOR GAS =    19698.
                         TOTAL ENERGY FLOW RATE =    19698.

LRC ID    R          Z        MACH      TG       VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP   IT
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     K      REK          VPK            THETA-K          TPK        DPK/DG          DPK/DPO          RPK

 5 14  1.00098   .27631  1.2269  5540.4  4925.0  11.362  .87320  .31275  .35817  .00532   .0000      .00  0
     1    .143199+01    .473159+04    .983044+01      .561330+04     .531699-02    .416153-02    .209520-05
 5  4  1.01174   .28117  1.2408  5525.2  4973.6  11.699  .87080  .30677  .35228  .00535   .0000      .00  3
     1    .137273+01    .478705+04    .101970+02      .559017+04     .532621-02    .410018-02    .209520-05
 5  5  1.03219   .29083  1.2816  5479.9  5116.1  12.771  .86366  .29025  .33605  .00000  1.2410   195.54  2

IP=  5                  MASS FLOW RATE OF GAS=       7.6095
              1--  MASS FLOW RATE OF PARTICLE  1 =   .13774-01
                        TOTAL MASS FLOW RATE =       7.6233

                     ENERGY FLOW RATE FOR GAS =      30609.
          1-- ENERGY FLOW RATE FOR PARTICLE  1 =     40.693
                      TOTAL ENERGY FLOW RATE =       30650.

LRC ID    R          Z          MACH     TG       VG      THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP   IT
     K      REK                  VPK             THETA-K          TPK        DPK/DG          DPK/DPO          RPK

 6 14   .99102   .28260  1.2229  5545.0  4911.0  11.349  .87392  .31498  .36042  .01628   .0000      .00  0
     1    .138713+01    .472453+04    .987319+01      .561173+04     .528745-02    .416440-02    .209520-05
     2    .297894+01    .462310+04    .905763+01      .563195+04     .109929-01    .865800-02    .292279-05
 6  4  1.00286   .28791  1.2389  5527.4  4967.3  11.750  .87115  .30798  .35358  .01634   .0000      .00  3
     1    .135790+01    .478347+04    .102653+02      .558823+04     .530477-02    .409812-02    .209520-05
     2    .295446+01    .467873+04    .944109+01      .561257+04     .110354-01    .852524-02    .292279-05
 6  4  1.01392   .29300  1.2574  5507.2  5032.0  12.221  .86796  .30028  .34596  .00534   .0000      .00  3
     1    .140325+01    .484010+04    .106486+02      .556669+04     .533778-02    .403552-02    .209520-05
 6  5  1.03501   .30316  1.2906  5469.9  5147.4  13.069  .86208  .28679  .33267  .00000  1.2427   195.81  2

IP=  7                  MASS FLOW RATE OF GAS=       10.629
              1--  MASS FLOW RATE OF PARTICLE  1 =   .29014-01          2--  MASS FLOW RATE OF PARTICLE  2 =   .30816-01
                        TOTAL MASS FLOW RATE =       10.689

                     ENERGY FLOW RATE FOR GAS =      42758.
          1-- ENERGY FLOW RATE FOR PARTICLE  1 =     85.680           2-- ENERGY FLOW RATE FOR PARTICLE  2 =   90.702
                      TOTAL ENERGY FLOW RATE =       42934.

LRC ID    R          Z          MACH     TG       VG      THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP   IT
     K      REK                  VPK             THETA-K          TPK        DPK/DG          DPK/DPO          RPK

 7 14   .97755   .29112  1.2177  5551.0  4892.5  11.323  .87457  .31792  .36340  .03895   .0000      .00  0
     1    .132545+01    .471543+04    .992278+01      .560960+04     .524898-02    .416821-02    .209520-05
     2    .286891+01    .461491+04    .914330+01      .562916+04     .109101-01    .846371-02    .292279-05
     3    .516558+01    .450729+04    .828440+01      .565005+04     .227718-01    .180831-01    .379506-05
 7  4   .99333   .29812  1.2392  5527.4  4968.4  11.877  .87114  .30835  .35396  .03919   .0000      .00  4
     1    .131878+01    .479064+04    .104291+02      .558155+04     .527805-02    .408245-02    .209520-05
     2    .287833+01    .468813+04    .962428+01      .560547+04     .109785-01    .849159-02    .292279-05
     3    .519217+01    .457690+04    .874750+01      .562938+04     .229321-01    .177374-01    .379506-05
 7  4  1.00420   .29580  1.2485  5517.1  5000.9  12.053  .86951  .30418  .34985  .01635   .0000      .00  3
     1    .135148+01    .481736+04    .105539+02      .557354+04     .531129-02    .406019-02    .209520-05
     2    .294099+01    .471215+04    .972976+01      .559916+04     .110408-01    .844011-02    .292279-05
 7  4  1.01546   .30107  1.2698  5493.7  5075.4  12.613  .86583  .29546  .34124  .00535   .0000      .00  3
     1    .144353+01    .487692+04    .109675+02      .555182+04     .535128-02    .399038-02    .209520-05
 7  5  1.03700   .31154  1.3095  5449.0  5211.9  13.665  .85878  .27975  .32575  .00000  1.2439   195.99  2
 7  4  1.00558   .30375  1.2591  5505.5  5038.3  12.391  .86768  .29998  .34572  .01638   .0000      .00  3
     1    .136932+01    .485152+04    .108483+02      .555960+04     .531866-02    .401815-02    .209520-05
     2    .296180+01    .474574+04    .100217+02      .558617+04     .110589-01    .835476-02    .292279-05
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   7  4  1.01705   .30918  1.2781  5484.5  5104.6  12.863  .86438  .29225  .33808  .00534   .0000      .00  2
        1     .138493+01      .491542+04      .112875+02      .553788+04    .534123-02      .394594-02    .209520-05
   7  5  1.03908   .32003  1.3187  5438.4  5244.4  13.963  .85711  .27625  .32228  .00000  1.2451  196.18  2

IP= 10                    MASS FLOW RATE OF GAS=   14.676
             1--  MASS FLOW RATE OF PARTICLE  1 =   .49381-01          2--  MASS FLOW RATE OF PARTICLE  2 =   .72003-01
             3--  MASS FLOW RATE OF PARTICLE  3 =   .83405-01
                       TOTAL MASS FLOW RATE =   14.880

                       ENERGY FLOW RATE FOR GAS =   59037.
           1-- ENERGY FLOW RATE FOR PARTICLE  1 =   145.78          2-- ENERGY FLOW RATE FOR PARTICLE  2 =   211.87
           3-- ENERGY FLOW RATE FOR PARTICLE  3 =   244.50
                     TOTAL ENERGY FLOW RATE =   59639.

LRC ID     R        Z       MACH     TG      VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF       ISP   IT
       K     REK             VPK           THETA-K          TPK          DPK/DG          DPK/DPO          RPK

   8 14   .95813   .30341  1.2104  5559.3  4866.7  11.267  .87618  .32203  .36754  .08621   .0000      .00  0
       1     .123471+01      .470518+04      .997794+01      .560653+04    .519639-02      .417353-02    .209520-05
       2     .270657+01      .460885+04      .923662+01      .562514+04    .107959-01      .867167-02    .292279-05
       3     .493407+01      .450356+04      .840376+01      .564556+04    .225293-01      .180946-01    .379506-05
       4     .886575+01      .436575+04      .729806+01      .567228+04    .476842-01      .382950-01    .495892-05
   8  4   .97897   .30211  1.2293  5538.4  4935.7  11.710  .87287  .31299  .35856  .08723   .0000      .00  4
       1     .130133+01      .475986+04      .102962+02      .559025+04    .525430-02      .411696-02    .209520-05
       2     .282989+01      .466072+04      .951745+01      .561204+04    .109292-01      .856345-02    .292279-05
       3     .511079+01      .455206+04      .865913+01      .563442+04    .225241-01      .178836-01    .379506-05
       4     .909888+01      .441125+04      .753314+01      .566268+04    .482195-01      .377812-01    .495892-05
   5  4   .99511   .30939  1.2524  5513.0  5014.8  12.304  .86587  .30302  .34875  .03923   .0000      .00  3
       1     .131695+01      .483659+04      .106259+02      .556310+04    .528168-02      .402511-02    .209520-05
       2     .286710+01      .473376+04      .100209+02      .558809+04    .109890-01      .837459-02    .292279-05
       3     .517134+01      .462156+04      .914352+01      .561312+04    .229589-01      .174967-01    .379506-05
   8  4  1.00766   .31526  1.2742  5489.0  5090.8  12.872  .86509  .29409  .33996  .01640   .0000      .00  3
       1     .137932+01      .490244+04      .112853+02      .554063+04    .532579-02      .395642-02    .209520-05
       2     .297309+01      .479467+04      .104507+02      .556794+04    .110788-01      .823018-02    .292279-05
   8  4  1.01945   .32094  1.2950  5465.8  5163.2  13.421  .86144  .28575  .33171  .00535   .0000      .00  3
       1     .141936+01      .496579+04      .117496+02      .551882+04    .535498-02      .385158-02    .209520-05
   8  5  1.04218   .33229  1.3372  5417.5  5307.6  14.559  .85383  .26942  .31554  .00000  1.2468  196.46  2
   8  4   .98047   .31318  1.2401  5526.7  4971.7  12.071  .87103  .30845  .35412  .08720   .0000      .00  4
       1     .126232+01      .480290+04      .106667+02      .557301+04    .524935-02      .406210-02    .209520-05
       2     .276712+01      .470362+04      .938910+01      .559596+04    .109215-01      .845136-02    .292279-05
       3     .502301+01      .459424+04      .903172+01      .561936+04    .228136-01      .176559-01    .379506-05
       4     .898278+01      .445183+04      .790525+01      .564879+04    .482137-01      .373092-01    .495892-05
   8  4   .99698   .32075  1.2667  5497.4  5064.6  12.763  .86642  .29732  .34316  .03931   .0000      .00  3
       1     .133370+01      .485311+04      .112349+02      .554572+04    .528979-02      .396674-02    .209520-05
       2     .288393+01      .477976+04      .104254+02      .557127+04    .110101-01      .825635-02    .292279-05
       3     .518818+01      .466644+04      .954399+01      .559716+04    .230099-01      .172548-01    .379506-05
   8  4  1.00985   .32688  1.2884  5473.3  5140.1  13.328  .86262  .28858  .33453  .01642   .0000      .00  3
       1     .136882+01      .495095+04      .117250+02      .552285+04    .532834-02      .389517-02    .209520-05
       2     .295242+01      .484570+04      .108844+02      .555029+04    .110879-01      .810556-02    .292279-05
   8  4  1.02197   .33280  1.3097  5449.5  5213.9  13.892  .85886  .28018  .32625  .00535   .0000      .00  3
       1     .139426+01      .501854+04      .122209+02      .550037+04    .535496-02      .381737-02    .209520-05
   8  5  1.04544   .34468  1.3557  5396.5  5376.7  15.155  .85051  .26268  .30889  .00000  1.2486  196.74  2

IP= 12                    MASS FLOW RATE OF GAS=   20.439
             1--  MASS FLOW RATE OF PARTICLE  1 =   .78247-01          2--  MASS FLOW RATE OF PARTICLE  2 =   .15044
             3--  MASS FLOW RATE OF PARTICLE  3 =   .20179             4--  MASS FLOW RATE OF PARTICLE  4 =   .24051
                       TOTAL MASS FLOW RATE =   21.090
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ENERGY FLOW RATE FOR GAS = 82224.
1-- ENERGY FLOW RATE FOR PARTICLE 1 = 230.99
2-- ENERGY FLOW RATE FOR PARTICLE 2 = 383.76
3-- ENERGY FLOW RATE FOR PARTICLE 3 = 591.45
4-- ENERGY FLOW RATE FOR PARTICLE 4 = 701.55
TOTAL ENERGY FLOW RATE = 84131.

LRC ID	K	R / REK	Z	MACH / VPK	TG	VG / THETA-K	THETA-G	TG/TGO / TPK	PG/PGO / DPK/DG	DG/DGO	SDK/DG / DPK/DPO	CF	ISP / RPK	IT
9 1		.95503	.30537	1.2092	3560.6	4862.8	11.257	.87638	.32267	.36819	.18280	.0000	.00	0
	1	.122008+01		.470133+04		.998497+01		.560605+04	.515532-02		.417436-02		.209520-05	
	2	.268035+01		.460766+04		.924978+01		.562449+04	.107796-01		.P57291-02		.292279-05	
	3	.489659+01		.450274+04		.842114+01		.564485+04	.224921-01		.180964-01		.379506-05	
	4	.881622+01		.436511+04		.731878+01		.567155+04	.476078-01		.383038-01		.495892-05	
	5	.163177+02		.417886+04		.579757+01		.570803+04	.967334-01		.778287-01		.670406-05	
9 4		.95848	.30683	1.2136	5555.8	4878.4	11.390	.87561	.32054	.36607	.18316	.0000	.00	3
	1	.123096+01		.471580+04		.100837+02		.560143+04	.519672-02		.415709-02		.209520-05	
	2	.263845+01		.462140+04		.934358+01		.562056+04	.107985-01		.863825-02		.292279-05	
	3	.492014+01		.451595+04		.851198+01		.564129+04	.225340-01		.180260-01		.379506-05	
	4	.884438+01		.437778+04		.740706+01		.566829+04	.475978-01		.381557-01		.495892-05	
	5	.163564+02		.419052+04		.588126+01		.570518+04	.969251-01		.775372-01		.670406-05	
9 4		.98096	.31671	1.2439	5522.6	4985.0	12.203	.87039	.30687	.35257	.08725	.0000	.00	3
	1	.126202+01		.481629+04		.107853+02		.556794+04	.524999-02		.404495-02		.209520-05	
	2	.276327+01		.471705+04		.100077+02		.559127+04	.109236-01		.841604-02		.292279-05	
	3	.501496+01		.460750+04		.915043+01		.561469+04	.225197-01		.175814-01		.379506-05	
	4	.897139+01		.446459+04		.802246+01		.564446+04	.482338-01		.371616-01		.495892-05	
9 4		.99759	.32438	1.2710	5492.7	5079.9	12.909	.86567	.29559	.34145	.03935	.0000	.00	3
	1	.133551+01		.489794+04		.113676+02		.554038+04	.529159-02		.394851-02		.209520-05	
	2	.288491+01		.479440+04		.105559+02		.556601+04	.110153-01		.821901-02		.292279-05	
	3	.518909+01		.468069+04		.967173+01		.559215+04	.230244-01		.171796-01		.379506-05	
9 4		1.01056	.33058	1.2933	5467.9	5157.5	13.[illegible]11	.86176	.28667	.33285	.01643	.0000	.00	3
	1	.137726+01		.496666+04		.118659+02		.551736+04	.533190-02		.387558-02		.209520-05	
	2	.296283+01		.485914+04		.110219+02		.554482+04	.110972-01		.806653-02		.292279-05	
9 4		1.02279	.33658	1.3147	5443.9	5231.2	14.057	.85798	.27829	.32435	.00536	.0000	.00	2
	1	.139844+01		.503493+04		.123689+02		.549471+04	.535812-02		.379776-02		.209520-05	
9 5		1.04651	.34862	1.3557	5396.5	5370.6	15.155	.85051	.26269	.30886	.00000	1.2492	196.84	2

IP= 15

MASS FLOW RATE OF GAS= 21.350
1-- MASS FLOW RATE OF PARTICLE 1 = .82788-01
2-- MASS FLOW RATE OF PARTICLE 2 = .13964
3-- MASS FLOW RATE OF PARTICLE 3 = .22044
4-- MASS FLOW RATE OF PARTICLE 4 = .27840
5-- MASS FLOW RATE OF PARTICLE 5 = .72760-01
TOTAL MASS FLOW RATE = 22.144

ENERGY FLOW RATE FOR GAS = 8[illegible]391.
1-- ENERGY FLOW RATE FOR PARTICLE 1 = 244.40
2-- ENERGY FLOW RATE FOR PARTICLE 2 = 410.82
3-- ENERGY FLOW RATE FOR PARTICLE 3 = 646.09
4-- ENERGY FLOW RATE FOR PARTICLE 4 = 812.04
5-- ENERGY FLOW RATE FOR PARTICLE 5 = 210.94
TOTAL ENERGY FLOW RATE = 88215.

LRC ID	K	R / REK	Z	MACH / VPK	TG	VG / THETA-K	THETA-G	TG/TGO / TPK	PG/PGO / DPK/DG	DG/DGO	SDK/DG / DPK/DPO	CF	ISP / RPK	IT
10 1		.93758	.31641	1.2030	5567.7	4840.8	11.188	.87750	.32621	.37173	.18122	.0000	.00	0
	1	.113679+01		.469134+04		.100158+02		.560329+04	.514428-02		.417835-02		.209520-05	
	2	.253085+01		.460142+04		.931533+01		.562038+04	.105847-01		.867973-02		.292279-05	
	3	.468233+01		.449859+04		.851092+01		.564081+04	.222857-01		.181063-01		.379506-05	
	4	.853207+01		.436198+04		.742806+01		.566742+04	.471907-01		.383353-01		.495892-05	

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 60  4  4.97567  9.76431   3.3980  3070.0 10153.5  17.005  .48385   .00649  .01342   .03465  .0000      .00  2
      1     .414575-01     .100737+05     .175174+02      .312536+04     .499600-02      .146472-05     .209520-05
      2     .825251-01     .100383+05     .177300+02      .314906+04     .100082-01      .293419-05     .292279-05
      3     .146182+00     .999509+04     .179791+02      .317665+04     .196287-01      .575470-05     .879506-05
 60  4  4.99436  9.77105   3.4076  3062.5 10169.5  17.042  .48267   .00650  .01347   .01468  .0000      .00  2
      1     .417863-01     .100899+05     .175557+02      .311760+04     .494129-02      .145457-05     .209520-05
      2     .831400-01     .100544+05     .177680+02      .314120+04     .973638-02      .286572-05     .292279-05
 60  4  5.00777  9.78040   3.4154  3056.2 10182.2  17.098  .48167   .00648  .01346   .00510  .0000      .00  2
      1     .407611-01     .101007+05     .175772+02      .311234+04     .509510-02      .149893-05     .209520-05
 60  5  5.01848  9.79621   3.4172  3055.0 10185.7  17.033  .48148   .00651  .01351   .00000 1.8407  290.08  2
 60  4  5.01399  9.80003   3.4168  3055.0 10184.3  17.076  .48148   .00647  .01345   .00509  .0000      .00  2
      1     .409360-01     .101031+05     .175630+02      .311089+04     .509295-02      .149518-05     .209520-05
 60  5  5.02434  9.81535   3.4193  3053.1 10188.7  17.033  .48118   .00648  .01347   .00000 1.8411  290.09  2
 60  4  5.00706  9.81069   3.4122  3058.3 10176.2  17.044  .48201   .00645  .01338   .01471  .0000      .00  2
      1     .405868-01     .100947+05     .175270+02      .311461+04     .495097-02      .144708-05     .209520-05
      2     .813034-01     .100592+05     .177382+02      .313827+04     .975410-02      .285095-05     .292279-05
 60  4  5.02021  9.81968   3.4162  3055.5 10183.5  17.004  .48156   .00646  .01345   .00507  .0000      .00  2
      1     .429415-01     .101054+05     .175479+02      .310946+04     .507424-02      .149134-05     .209520-05
 60  5  5.03021  9.83450   3.4213  3051.2 10191.7  17.033  .48089   .00645  .01342   .00000 1.8415  290.15  2
 60  4  5.02642  9.83936   3.4185  3053.4 10186.8  17.005  .48123   .00645  .01340   .01508  .0000      .00  2
      1     .422553-01     .101076+05     .175323+02      .310805+04     .507945-02      .148768-05     .209520-05
 60  5  5.03608  9.85367   3.4234  3049.3 10194.7  17.033  .48059   .00643  .01338   .00000 1.8418  290.21  2
 60  4  4.96495  9.83191   3.3855  3079.0 10130.6  16.856  .48527   .00640  .01318   .07331  .0000      .00  3
      1     .409368-01     .100518+05     .173785+02      .313473+04     .493078-02      .142042-05     .209520-05
      2     .813187-01     .100164+05     .175916+02      .315866+04     .978016-02      .281740-05     .292279-05
      3     .143551+00     .997149+04     .178392+02      .318692+04     .194304-01      .559736-05     .379506-05
      4     .266920+00     .989474+04     .182091+02      .324186+04     .391642-01      .112621-02     .495892-05
 60  4  5.00163  9.84446   3.4055  3063.1 10164.4  16.959  .48276   .00641  .01327   .03464  .0000      .00  2
      1     .407391-01     .100838+05     .174586+02      .311921+04     .499664-02      .144894-05     .209520-05
      2     .812732-01     .100482+05     .176699+02      .314301+04     .100079-01      .290211-05     .292279-05
      3     .144118+00     .100031+05     .179177+02      .317062+04     .196361-01      .569415-05     .379506-05
 60  4  5.01974  9.85038   3.4133  3057.3 10178.0  16.956  .48184   .00644  .01336   .01465  .0000      .00  2
      1     .425247-01     .100975+05     .174972+02      .311167+04     .493180-02      .143951-05     .209520-05
      2     .839222-01     .100639+05     .177080+02      .313536+04     .971570-02      .283585-05     .292279-05
 60  4  5.03264  9.85904   3.4207  3051.4 10190.0  17.006  .48091   .00642  .01336   .00508  .0000      .00  2
      1     .416083-01     .101099+05     .175171+02      .310663+04     .509469-02      .148405-05     .209520-05

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PARTICLE IMPACT, WALL (R,Z)=  5.04196  9.87285      AREA RATIO=   25.421
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 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =    9.873 :

    VELOCITY = 10109.92 FT/SEC, MASS FLUX =   .163 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE =  .484 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

           .081 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .323 MILS AT Z/RT =   9.882

 58  5  5.04196  9.87285   3.4255  3047.4 10197.6  17.033  .48029   .00640  .01335   .00509 1.8422  290.27  2
      1     .421710-01     .101099+05     .175171+02      .310663+04     .509442-02      .148405-05     .209520-05
 60  5  5.04784  9.89205   3.4275  3045.5 10200.6  17.033  .47999   .00638  .01329   .00510 1.8426  290.33  2
      1     .416043-01     .101123+05     .175033+02      .310516+04     .509589-02      .148027-05     .209520-05
 60  4  5.03241  9.89011   3.4177  3053.3 10184.4  16.953  .48121   .00639  .01327   .01467  .0000      .00  2
      1     .415891-01     .101034+05     .174667+02      .310915+04     .494104-02      .143257-05     .209520-05
      2     .822553-01     .100686+05     .176773+02      .313248+04     .973158-02      .282151-05     .292279-05
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07/26/82  09:49:57 MA     0425AA410    MA              10    300                                    DATE 072682        PAGE   90

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  10.427 :

    VELOCITY = 10172.40 FT/SEC, MASS FLUX =   .151 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE =  .439 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

           .061 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .244 MILS AT Z/RT =  10.435

 60  5  5.20967 10.42747  3.4699  3006.8 10260.9  16.678  .47389  .00587  .01238  .00505  1.8528  291.93  2
        1     .380469-01      .101724+05     .171171+02     .306759+04     .505473-02     .136752-05     .209520-05

IP= 63                          MASS FLOW RATE OF GAS=    166.49
              1--  MASS FLOW RATE OF PARTICLE  1 =     .75102                    2--  MASS FLOW RATE OF PARTICLE  2 =    1.5029
              3--  MASS FLOW RATE OF PARTICLE  3 =    3.0064                     4--  MASS FLOW RATE OF PARTICLE  4 =    6.0316
              5--  MASS FLOW RATE OF PARTICLE  5 =   11.313                      6--  MASS FLOW RATE OF PARTICLE  6 =   52.838
                                TOTAL MASS FLOW RATE =   241.94

                             ENERGY FLOW RATE FOR GAS =   .65530+06
             1-- ENERGY FLOW RATE FOR PARTICLE  1 =    2208.9                   2-- ENERGY FLOW RATE FOR PARTICLE  2 =    4466.1
             3-- ENERGY FLOW RATE FOR PARTICLE  3 =    9011.4                   4-- ENERGY FLOW RATE FOR PARTICLE  4 =    18256.
             5-- ENERGY FLOW RATE FOR PARTICLE  5 =    34708.                   6-- ENERGY FLOW RATE FOR PARTICLE  6 =    .16143+06
                               TOTAL ENERGY FLOW RATE =   .88538+06

LRC ID      R          Z          MACH      TG       VG     THETA-G  TG/TG0   PG/PG0  DG/DG0   SDK/DG    CF       ISP    IT
        K         REK             VPK              THETA-K          TPK         DPK/DG          DPK/DP0             RPK

 61  3   .00000  3.43440  2.0934  4405.9  7493.5     .000  .69439  .03062  .04409 1.13573   .0000      .00  5
        1      .657424-01      .741929+04     .000000        .446754+04     .546779-02     .526847-05     .209520-05
        2      .176231+00      .735087+04     .000000        .449379+04     .115739-01     .112485-02     .292279-05
        3      .349626+00      .727555+04     .000000        .452277+04     .251207-01     .242050-02     .379506-05
        4      .654561+00      .718122+04     .000000        .456263+04     .551501-01     .551397-02     .495892-05
        5      .131145+01      .703069+04     .000000        .462277+04     .119615+00     .115255-01     .670406-05
        6      .661099+01      .537019+04     .000000        .484779+04     .915702+00     .885212-01     .139242-04
 61  4  4.21957  9.20328  3.0310  3390.3  9517.8  15.814  .53436  .00647  .01211  .48490   .0000      .00  4
        1      .355676-01      .944374+04     .164036+02     .343816+04     .465081-02     .123079-05     .209520-05
        2      .692248-01      .941019+04     .166176+02     .346565+04     .924758-02     .244727-05     .292279-05
        3      .119000+00      .936873+04     .168465+02     .352145+04     .184517-01     .488305-05     .379506-05
        4      .215621+00      .929768+04     .171752+02     .367464+04     .371182-01     .982292-05     .495892-05
        5      .426166+00      .917086+04     .176532+02     .408091+04     .717358-01     .189841-02     .670406-05
        6      .214890+01      .552789+04     .190540+02     .416700+04     .343693+00     .909547-02     .139242-04
 61  4  5.03860 10.28935  3.3828  3076.7 10118.8  16.333  .48490  .00592  .01222  .14706   .0000      .00  3
        1      .379367-01      .100399+05     .168564+02     .313332+04     .485714-02     .129664-05     .209520-05
        2      .752743-01      .100443+05     .170678+02     .315780+04     .964720-02     .257539-05     .292279-05
        3      .132028+00      .996029+04     .173074+02     .318720+04     .192423-01     .513683-05     .379506-05
        4      .243840+00      .988547+04     .176640+02     .324519+04     .384245-01     .102576-02     .495892-05
        5      .480208+00      .975899+04     .181617+02     .342242+04     .748870-01     .199913-02     .670406-05
 61  4  5.14748 10.39374  3.4392  3034.0 10204.2  16.489  .47817  .00589  .01232  .07290   .0000      .00  3
        1      .387975-01      .101220+05     .169956+02     .309180+04     .492137-02     .132453-05     .209520-05
        2      .765800-01      .100868+05     .172015+02     .311583+04     .975393-02     .262516-05     .292279-05
        3      .134585+00      .100421+05     .174385+02     .314414+04     .195114-01     .519749-05     .379506-05
        4      .249323+00      .996642+04     .177950+02     .319574+04     .389180-01     .104744-02     .495892-05
 61  4  5.19590 10.42174  3.4549  3018.6 10236.4  16.565  .47575  .00588  .01236  .03450   .0000      .00  2
        1      .390545-01      .101520+05     .170584+02     .307716+04     .497960-02     .134536-05     .209520-05
        2      .768768-01      .101174+05     .172624+02     .310071+04     .995872-02     .269050-05     .292279-05
        3      .135348+00      .100724+05     .174983+02     .312860+04     .199661-01     .528628-05     .379506-05
 61  4  5.20340 10.43319  3.4653  3010.3 10253.2  16.638  .47444  .00586  .01236  .01470   .0000      .00  2
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          1    .367403-01     .100705+05    .167078+02    .311456+04    .485256-02    .126150-05    .209520-05
          2    .729932-01     .100345+05    .169160+02    .313920+04    .965135-02    .250347-05    .292279-05
          3    .127993+00     .999084+04    .171512+02    .316853+04    .192319-01    .498857-05    .379506-05
          4    .236313+00     .991646+04    .175019+02    .322477+04    .385543-01    .994872-05    .495892-05
          5    .466430+00     .979014+04    .179971+02    .339391+04    .746708-01    .193689-02    .670406-05
  61   4  5.29283 10.62965  3.4560  3015.4 10234.4  16.362  .47524  .00569  .01197  .07283   .0000     .00  2
          1    .374814-01     .101509+05    .168515+02    .307414+04    .492260-02    .125734-05    .209520-05
          2    .741420-01     .101153+05    .170536+02    .309842+04    .975504-02    .255110-05    .292279-05
          3    .130263+00     .100707+05    .172852+02    .312684+04    .192891-01    .504441-05    .379506-05
          4    .242243+00     .999529+04    .176341+02    .317746+04    .385598-01    .101625-02    .495892-05
  61   4  5.27490 10.65437  3.4748  3000.8 10265.0  16.441  .47294  .00568  .01201  .03447   .0000     .00  2
          1    .376990-01     .101798+05    .169183+02    .306011+04    .497413-02    .130575-05    .209520-05
          2    .744241-01     .101444+05    .171176+02    .308412+04    .994378-02    .261025-05    .292279-05
          3    .130942+00     .100994+05    .173473+02    .311221+04    .195564-01    .513365-05    .379506-05
  61   4  5.27482 10.66349  3.4837  2993.9 10279.4  16.489  .47186  .00565  .01205  .01467   .0000     .00  2
          1    .374957-01     .101928+05    .169495+02    .305392+04    .494520-02    .129959-05    .209520-05
          2    .741223-01     .101575+05    .171479+02    .307775+04    .972736-02    .255652-05    .292279-05

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PARTICLE IMPACT, WALL (R,Z)=  5.28408 10.67765      AREA RATIO=   27.921
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 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  10.678 :

    VELOCITY = 10171.62 FT/SEC, MASS FLUX =   .428 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.610 MICRONS, IMPACT ANGLE =  .568 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

          .415 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       1.659 MILS AT Z/RT =  10.719

  61   5  5.28408 10.67765  3.4884  2990.2 10286.8  16.514  .47126  .00566  .01201  .01476  1.8573  292.64  2
          1    .370268-01     .101989+05    .169552+02    .305084+04    .502014-02    .131709-05    .209520-05
          2    .751141-01     .101575+05    .171479+02    .307775+04    .974426-02    .255652-05    .292279-05
  61   5  5.29235 10.70559  3.4880  2990.5 10286.2  16.433  .47132  .00566  .01201  .01470  1.8578  292.72  2
          1    .387639-01     .102017+05    .169373+02    .304902+04    .499761-02    .131196-05    .209520-05
          2    .773555-01     .101606+05    .171299+02    .307585+04    .970734-02    .254855-05    .292279-05
  61   4  5.27711 10.71273  3.4805  2995.8 10273.1  16.427  .47214  .00562  .01191  .03451   .0000     .00  2
          1    .369190-01     .101867+05    .168842+02    .305588+04    .497993-02    .129655-05    .209520-05
          2    .735161-01     .101499+05    .170813+02    .308065+04    .995628-02    .259177-05    .292279-05
          3    .129020+00     .101061+05    .173105+02    .310815+04    .195777-01    .509657-05    .379506-05
  61   5  5.30882 10.76140  3.4935  2985.5 10293.9  16.433  .47053  .00560  .01190  .01474  1.8588  292.88  2
          1    .374492-01     .102074+05    .169007+02    .304541+04    .500558-02    .130211-05    .209520-05
          2    .753330-01     .101665+05    .170930+02    .307215+04    .973570-02    .253241-05    .292279-05
  61   4  5.26036 10.74799  3.4667  3005.9 10249.8  16.305  .47374  .00559  .01179  .07284   .0000     .00  2
          1    .368019-01     .101653+05    .167835+02    .306532+04    .492685-02    .126935-05    .209520-05
          2    .729160-01     .101294+05    .169833+02    .308981+04    .976380-02    .251550-05    .292279-05
          3    .128064+00     .100848+05    .172119+02    .311828+04    .192953-01    .497115-05    .379506-05
          4    .237141+00     .100095+05    .175566+02    .316849+04    .385568-01    .100109-02    .495892-05
  61   4  5.29530 10.77117  3.4857  2992.9 10277.8  16.351  .47169  .00559  .01186  .03441   .0000     .00  2
          1    .379501-01     .101934+05    .168487+02    .305173+04    .496444-02    .128675-05    .209520-05
          2    .751111-01     .101555+05    .170444+02    .307709+04    .992586-02    .257269-05    .292279-05
          3    .130563+00     .101127+05    .172737+02    .310412+04    .195181-01    .505830-05    .379506-05
  61   5  5.32530 10.81730  3.4990  2980.6 10501.6  16.433  .46975  .00554  .01179  .01478  1.8597  293.08  2
          1    .363163-01     .102132+05    .168669+02    .304174+04    .501423-02    .129255-05    .209520-05
          2    .735156-01     .101725+05    .170583+02    .306844+04    .976329-02    .251635-05    .292279-05
  61   4  5.31348 10.82968  3.4901  2987.2 10286.8  16.354  .47080  .00555  .01175  .05449   .0000     .00  2
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 61  4  5.27472 11.01968   3.4484  3017.2 10215.0  15.939  .47553   .00535  .01121   .14600    .0000      .00  3
      1     .349016-01      .101323+05      .164281+02      .307671+04      .485043-02      .119109-05     .209520-05
      2     .693534-01      .100959+05      .166296+02      .310187+04      .965627-02      .235144-05     .292279-05
      3     .121195+00      .100519+05      .168551+02      .313116+04      .191683-01      .469734-05     .379506-05
      4     .223004+00      .997830+04      .171921+02      .318456+04      .381456-01      .934787-05     .495892-05
      5     .441332+00      .985206+04      .176791+02      .333981+04      .741847-01      .181795-02     .670406-05
 61  4  5.37499 11.11283   3.4977  2978.4 10294.1  16.110  .46941   .00530  .01130   .07264    .0000      .00  2
      1     .355539-01      .102088+05      .165832+02      .303874+04      .491875-02      .121454-05     .209520-05
      2     .707909-01      .101704+05      .167759+02      .306459+04      .975229-02      .240805-05     .292279-05
      3     .123176+00      .101273+05      .169977+02      .309246+04      .192337-01      .474920-05     .379506-05
      4     .227206+00      .100525+05      .173300+02      .314162+04      .387378-01      .956518-05     .495892-05
 61  4  5.40607 11.12977   3.5157  2964.6 10323.0  16.219  .46724   .00529  .01132   .03449    .0000      .00  2
      1     .348702-01      .102345+05      .166487+02      .302639+04      .497709-02      .123125-05     .209520-05
      2     .702290-01      .101949+05      .168380+02      .305280+04      .994425-02      .246005-05     .292279-05
      3     .122259+00      .101526+05      .170592+02      .307980+04      .195675-01      .484056-05     .379506-05
 61  5  5.42554 11.16008   3.5225  2959.5 10334.0  16.192  .46543   .00529  .01134   .01477   1.8556   293.95  2
      1     .360586-01      .102473+05      .166618+02      .301993+04      .495984-02      .123606-05     .209520-05
      2     .720088-01      .102071+05      .168494+02      .304660+04      .977957-02      .242311-05     .292279-05
 61  4  5.42453 11.18999   3.5191  2961.6 10327.8  16.149  .46676   .00526  .01127   .03440    .0000      .00  2
      1     .357075-01      .102413+05      .166168+02      .302221+04      .496450-02      .122254-05     .209520-05
      2     .712581-01      .102016+05      .168052+02      .304068+04      .991745-02      .244210-05     .292279-05
      3     .123452+00      .101592+05      .170252+02      .307578+04      .195128-01      .480459-05     .379506-05
 61  5  5.44226 11.21765   3.5279  2954.6 10341.5  16.192  .46566   .00523  .01124   .01481   1.8665   294.10  2
      1     .349886-01      .102529+05      .166287+02      .301633+04      .499731-02      .122395-05     .209520-05
      2     .703508-01      .102128+05      .168156+02      .304302+04      .980770-02      .240797-05     .292279-05
 61  4  5.41303 11.23502   3.5090  2968.5 10310.1  16.070  .46784   .00520  .01112   .07273    .0000      .00  2
      1     .346266-01      .102231+05      .165205+02      .302995+04      .492741-02      .119738-05     .209520-05
      2     .692538-01      .101844+05      .167110+02      .305606+04      .977065-02      .237431-05     .292279-05
      3     .120603+00      .101412+05      .169300+02      .308398+04      .192589-01      .467998-05     .379506-05
      4     .222666+00      .100665+05      .172580+02      .313286+04      .387755-01      .942262-05     .495892-05
 61  4  5.43376 11.22015   3.5221  2959.0 10332.0  16.147  .46634   .00525  .01122   .03442    .0000      .00  2
      1     .352638-01      .102447+05      .166008+02      .302013+04      .496752-02      .121774-05     .209520-05
      2     .705724-01      .102049+05      .167888+02      .304663+04      .992194-02      .243228-05     .292279-05
      3     .122418+00      .101625+05      .170079+02      .307378+04      .195292-01      .478745-05     .379506-05
 61  5  5.45064 11.24651   3.5276  2954.9 10341.0  16.113  .46570   .00523  .01124   .01475   1.8670   294.17  2
      1     .366210-01      .102557+05      .166117+02      .301456+04      .497685-02      .122247-05     .209520-05
      2     .725214-01      .102155+05      .167985+02      .304125+04      .977300-02      .240055-05     .292279-05
 61  4  5.44760 11.26543   3.5249  2956.5 10335.9  16.098  .46596   .00521  .01118   .03436    .0000      .00  2
      1     .358097-01      .102497+05      .165763+02      .301702+04      .495854-02      .121096-05     .209520-05
      2     .712261-01      .102099+05      .167639+02      .304357+04      .990235-02      .241832-05     .292279-05
      3     .123138+00      .101674+05      .169822+02      .307079+04      .194952-01      .476100-05     .379506-05
 61  5  5.46312 11.28975   3.5317  2951.2 10346.7  16.113  .46512   .00519  .01116   .01478   1.8677   294.28  2
      1     .357413-01      .102597+05      .165853+02      .301194+04      .498356-02      .121572-05     .209520-05
      2     .712179-01      .102196+05      .167721+02      .303862+04      .979516-02      .238950-05     .292279-05
 61  4  5.46143 11.31076   3.5287  2953.2 10341.2  16.074  .46545   .00517  .01112   .03436    .0000      .00  2
      1     .356542-01      .102546+05      .165512+02      .301395+04      .495946-02      .120455-05     .209520-05
      2     .709299-01      .102148+05      .167386+02      .304052+04      .990202-02      .240519-05     .292279-05
      3     .122607+00      .101722+05      .169561+02      .306782+04      .194942-01      .473515-05     .379506-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1        ALFA*THRUST DECREMENTS=      -.58499        MASS FLOW DECREMENTS=      -.00645
PARTICLE GROUP 2        ALFA*THRUST DECREMENTS=      -.68101        MASS FLOW DECREMENTS=      -.00749

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  11.333 :

    VELOCITY = 10237.34 FT/SEC, MASS FLUX =   .399 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.612 MICRONS, IMPACT ANGLE =  .571 DEG.
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CALCULA E EMPIRICAL EROSION RATES

        .408 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      1.633 MILS AT Z/RI =  11.374

 61  5  5.47562 11.33301  3.5359  2947.5 10552.3  16.113  .46454  .00515  .01109  .01481  1.8684  294.40  2
        1    .349607-01    .102639+05    .165604+02    .300927+04    .499048-02    .120900-05    .209520-05
        2    .700196-01    .102239+05    .167469+02    .303598+04    .981761-02    .237849-05    .292279-05

IP= 63                   MASS FLOW RATE OF GAS=      166.68
          1--  MASS FLOW RATE OF PARTICLE  1 =      .74704                 2--  MASS FLOW RATE OF PARTICLE  2 =    1.4956
          3--  MASS FLOW RATE OF PARTICLE  3 =      3.0057                 4--  MASS FLOW RATE OF PARTICLE  4 =    6.0302
          5--  MASS FLOW RATE OF PARTICLE  5 =      11.309                 6--  MASS FLOW RATE OF PARTICLE  6 =    52.835
                       TOTAL MASS FLOW RATE =      242.11

                      ENERGY FLOW RATE FOR GAS =   .65559+06
         1-- ENERGY FLOW RATE FOR PARTICLE  1 =    2187.6             2-- ENERGY FLOW RATE FOR PARTICLE  2 =   4441.4
         3-- ENERGY FLOW RATE FOR PARTICLE  3 =    8936.4             4-- ENERGY FLOW RATE FOR PARTICLE  4 =   18215.
         5-- ENERGY FLOW RATE FOR PARTICLE  5 =    34627.             6-- ENERGY FLOW RATE FOR PARTICLE  6 =   .16210+06
                     TOTAL ENERGY FLOW RATE =      .89614+06

LRC ID      R          Z        MACH     TG       VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP    IT
     K         REK               VPK              THETA-K          TPK      DPK/DG          DPK/DPO           RPK

 62  3   .00000  3.69740  2.1479  4330.9  7622.7    .000  .68257  .02549  .03734 1.15993   .0000     .00  5
     1     .569722-01     .754758+04     .000000      .439799+04     .551442-02     .449957-05     .209520-05
     2     .147715+00     .748511+04     .000000      .442586+04     .117832-01     .961552-05     .292279-05
     3     .297526+00     .740618+04     .000000      .445623+04     .254048-01     .207308-02     .379506-05
     4     .559520+00     .731121+04     .000000      .449773+04     .555491-01     .455739-02     .495892-05
     5     .112084+01     .716099+04     .000000      .456011+04     .121425+00     .990849-02     .670406-05
     6     .565724+01     .550073+04     .000000      .479271+04     .939950+00     .767017-01     .139242-04
 62  4  4.54782 10.17027  3.1196  3302.2  9667.5  15.126  .52044  .00565  .01085  .46395   .0000     .00  4
     1     .328946-01     .959089+04     .157078+02    .335368+04     .470029-02     .111476-05     .209520-05
     2     .646742-01     .955551+04     .159328+02    .337871+04     .933381-02     .221367-05     .292279-05
     3     .110904+00     .951570+04     .161673+02    .342085+04     .185441-01     .439805-05     .379506-05
     4     .199133+00     .944745+04     .164989+02    .353156+04     .369989-01     .877494-05     .495892-05
     5     .391664+00     .932368+04     .169884+02    .384556+04     .705964-01     .167649-02     .670406-05
     6     .196260+01     .868798+04     .184500+02    .416700+04     .323674+00     .767648-02     .139242-04
 62  4  5.35812 11.28260  3.4720  2996.2 10248.7  15.826  .47221  .00314  .01088  .14561   .0000     .00  3
     1     .330333-01     .101647+05     .162949+02    .305688+04     .485583-02     .115475-05     .209520-05
     2     .671355-01     .101274+05     .164918+02    .308255+04     .962350-02     .228856-05     .292279-05
     3     .117198+00     .100837+05     .167121+02    .311175+04     .191286-01     .454845-05     .379506-05
     4     .215560+00     .100103+05     .170407+02    .316399+04     .380301-01     .904355-05     .495892-05
     5     .427598+00     .988398+04     .175209+02    .331309+04     .739734-01     .175914-02     .670406-05
 62  4  5.45332 11.36502  3.5186  2960.1 10323.7  15.976  .46652  .00512  .01098  .07250   .0000     .00  3
     1     .349629-01     .102380+05     .164530+02    .302076+04     .491276-02     .117887-05     .209520-05
     2     .695179-01     .101990+05     .166322+02    .304711+04     .974237-02     .233778-05     .292279-05
     3     .120464+00     .101558+05     .168588+02    .307508+04     .191916-01     .460525-05     .379506-05
     4     .221362+00     .100813+05     .171829+02    .312369+04     .386483-01     .927405-05     .495892-05
 62  4  5.47120 11.34284  3.5320  2950.3 10345.9  16.078  .46498  .00514  .01106  .03439   .0000     .00  2
     1     .349907-01     .102582+05     .165342+02    .301176+04     .496359-02     .119959-05     .209520-05
     2     .699326-01     .102183+05     .167213+02    .303837+04     .990897-02     .239499-05     .292279-05
     3     .121164+00     .101757+05     .169381+02    .306572+04     .195165-01     .471712-05     .379506-05
 62  5  5.48447 11.36365  3.5387  2945.0 10356.2  16.113  .46415  .00512  .01104  .01485  1.8689  294.47  2
     1     .344266-01     .102669+05     .165436+02    .300737+04     .499417-02     .120424-05     .209520-05
     2     .691843-01     .102267+05     .167297+02    .303410+04     .985111-02     .237056-05     .292279-05
 62  4  5.47853 11.36690  3.5395  2948.1 10349.3  16.081  .46464  .00512  .01102  .03441   .0000     .00  2
     1     .345269-01     .102608+05     .165220+02    .301011+04     .495644-02     .119597-05     .209520-05
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       2     .692312-01     .102210+05     .167088+02     .303674+04     .991368-02     .238732-05     .292279-05
       3     .120142+00     .101783+05     .169249+02     .306419+04     .195329-01     .470375-05     .379506-05
  62   5   5.49111 11.38665   3.5377  2945.9 10354.8  16.034   .46428   .00515  .01105   .01476  1.8693  294.53  2
       1     .360993-01     .102690+05     .165304+02     .300597+04     .497191-02     .120074-05     .209520-05
       2     .714407-01     .102289+05     .167164+02     .303270+04     .979183-02     .236477-05     .292279-05
  62   4   5.48951 11.40301   3.5358  2947.0 10351.1  16.025   .46447   .00511  .01100   .03431   .0000     .00  2
       1     .354454-01     .102645+05     .165031+02     .300767+04     .495191-02     .119072-05     .209520-05
       2     .704251-01     .102249+05     .166895+02     .303433+04     .985303-02     .237644-05     .292279-05
       3     .121628+00     .101821+05     .169049+02     .306179+04     .194756-01     .468327-05     .379506-05
  62   5   5.50102 11.42111   3.5408  2943.1 10359.1  16.034   .46385   .00510  .01099   .01478  1.8698  294.62  2
       1     .353872-01     .102722+05     .165097+02     .300391+04     .497571-02     .119544-05     .209520-05
       2     .703960-01     .102321+05     .166958+02     .303065+04     .980678-02     .235615-05     .292279-05
  62   4   5.50049 11.43916   3.5387  2944.4 10355.3  16.008   .46406   .00508  .01096   .03431   .0000     .00  2
       1     .352104-01     .102687+05     .164834+02     .300525+04     .495278-02     .118584-05     .209520-05
       2     .700309-01     .102288+05     .166698+02     .303193+04     .985275-02     .236622-05     .292279-05
       3     .121004+00     .101859+05     .168846+02     .305945+04     .194766-01     .466326-05     .379506-05
  62   5   5.51093 11.45559   3.5440  2940.3 10363.3  16.034   .46341   .00507  .01094   .01480  1.8704  294.71  2
       1     .347393-01     .102754+05     .164900+02     .300183+04     .497986-02     .119016-05     .209520-05
       2     .694200-01     .102354+05     .166758+02     .302858+04     .952234-02     .234750-05     .292279-05
  62   4   5.49353 11.49535   3.5292  2950.9 10338.9  15.910   .46507   .00503  .01082   .07242   .0000     .00  2
       1     .345670-01     .102527+05     .163861+02     .301171+04     .491082-02     .116155-05     .209520-05
       2     .687290-01     .102135+05     .165742+02     .303819+04     .973883-02     .230346-05     .292279-05
       3     .118980+00     .101703+05     .167883+02     .306629+04     .191747-01     .453526-05     .379506-05
       4     .218296+00     .100959+05     .171084+02     .311465+04     .355952-01     .912959-05     .495892-05
  62   4   5.51025 11.47132   3.5420  2941.6 10359.8  16.019   .46361   .00506  .01090   .03434   .0000     .00  2
       1     .346032-01     .102721+05     .164665+02     .300309+04     .495652-02     .115101-05     .209520-05
       2     .691270-01     .102522+05     .166527+02     .302979+04     .985867-02     .235621-05     .292279-05
       3     .119701+00     .101393+05     .168669+02     .305737+04     .19496?-01     .464561-05     .379506-05

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PARTICLE IMPACT, WALL (R,Z)=  5.51975 11.48629      AREA RATIO=   30.465
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 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  11.486 :

    VELOCITY = 10216.36 FT/SEC, MASS FLUX =   .907 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.010 MICRONS, IMPACT ANGLE =  .715 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

         2.007 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       5.028 MILS AT Z/RT =  11.646

  62   5   5.51975 11.48629   3.5468  2937.8 10367.2  16.034   .46302   .00504  .01089   .03435  1.8709  294.75  2
       1     .342079-01     .102783+05     .164732+02     .299997+04     .495341-02     .118545-05     .209520-05
       2     .686003-01     .102383+05     .166557+02     .302673+04     .985588-02     .233975-05     .292279-05
       3     .121011+00     .101893+05     .168669+02     .305737+04     .195293-01     .464561-05     .379506-05
  62   5   5.54614 11.57841   3.5520  2933.2 10374.2  15.956   .46228   .00499  .01079   .03426  1.8725  295.01  3
       1     .345867-01     .102869+05     .164225+02     .299444+04     .497060-02     .117180-05     .209520-05
       2     .689059-01     .102469+05     .166072+02     .302125+04     .981587-02     .231404-05     .292279-05
       3     .120848+00     .101983+05     .168141+02     .305176+04     .194782-01     .459189-05     .379506-05
  62   4   5.44116 11.54682   3.4943  2976.4 10280.6  15.693   .46909   .00496  .01057   .14523   .0000     .00  3
       1     .330742-01     .101963+05     .161663+02     .303749+04     .485388-02     .112099-05     .209520-05
       2     .659091-01     .101582+05     .163596+02     .306361+04     .961670-02     .222095-05     .292279-05
       3     .114561+00     .101146+05     .165748+02     .309281+04     .190956-01     .441019-05     .379506-05
       4     .209907+00     .100416+05     .168953+02     .314414+04     .379360-01     .876124-05     .495892-05
       5     .416269+00     .991524+04     .173695+02     .328759+04     .737256-01     .170268-02     .670406-05
  62   4   5.53366 11.62604   3.5407  2940.8 10354.7  15.867   .46348   .00494  .01065   .07245   .0000     .00  2
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62  4  5.60924 12.08905   3.5389  2937.3 10343.3  15.437  .46294   .00462  .00998   .14422   .0000     .00  3
    1     .318900-01     .102586+05     .159167+02     .299916+04     .485863-02     .105550-05     .209520-05
    2     .634562-01     .102195+05     .161055+02     .302593+04     .957901-02     .208978-05     .292279-05
    3     .109934+00     .101747+05     .163110+02     .305590+04     .189921-01     .414354-05     .379506-05
    4     .199455+00     .101032+05     .166175+02     .310521+04     .375631-01     .821666-05     .495892-05
    5     .395159+00     .397687+04     .170790+02     .323895+04     .731455-01     .159576-02     .670406-05
62  4  5.67527 12.09179   3.5776  2908.9 10405.7  15.651  .45846   .00464  .01012   .07221   .0000     .00  2
    1     .321029-01     .103176+05     .160941+02     .297172+04     .490494-02     .108519-05     .209520-05
    2     .643201-01     .102776+05     .162794+02     .299867+04     .971529-02     .214945-05     .292279-05
    3     .112261+00     .102309+05     .164816+02     .302893+04     .191213-01     .423047-05     .379506-05
    4     .203666+00     .101601+05     .167886+02     .307490+04     .384670-01     .851050-05     .495892-05
62  5  5.70510 12.13978   3.5893  2900.2 10424.0  15.651  .45708   .00465  .01012   .03403  1.8809   296.36  3
    1     .327834-01     .103965+05     .161158+02     .296219+04     .494708-02     .109436-05     .209520-05
    2     .653038-01     .102963+05     .162995+02     .298923+04     .976808-02     .216082-05     .292279-05
    3     .113682+00     .102499+05     .164998+02     .301966+04     .195131-01     .427250-05     .379506-05
62  4  5.69044 12.14214   3.5821  2905.1 10411.8  15.641  .45785   .00461  .01006   .07223   .0000     .00  2
    1     .316993-01     .103229+05     .160723+02     .296840+04     .490630-02     .107871-05     .209520-05
    2     .636592-01     .102829+05     .162569+02     .299540+04     .971682-02     .213637-05     .292279-05
    3     .111231+00     .102362+05     .164582+02     .302571+04     .191238-01     .420452-05     .379506-05
    4     .201933+00     .101653+05     .167636+02     .307165+04     .384840-01     .846120-05     .495892-05
62  5  5.71837 12.18715   3.5934  2896.6 10429.4  15.651  .45652   .00459  .01005   .03406  1.8815   296.47  2
    1     .320542-01     .103405+05     .160917+02     .295953+04     .495283-02     .108811-05     .209520-05
    2     .642034-01     .103002+05     .162751+02     .298660+04     .977920-02     .214845-05     .292279-05
    3     .112074+00     .102331+05     .164748+02     .301705+04     .195256-01     .424659-05     .379506-05
62  4  5.71319 12.21774   3.5872  2900.7 10418.9  15.589  .45716   .00457  .00999   .07210   .0000     .00  2
    1     .319408-01     .103309+05     .160387+02     .296349+04     .489867-02     .106965-05     .209520-05
    2     .638703-01     .102907+05     .162227+02     .299055+04     .969960-02     .211795-05     .292279-05
    3     .111258+00     .102440+05     .164228+02     .302091+04     .190852-01     .416799-05     .379506-05
    4     .201488+00     .101732+05     .167264+02     .306680+04     .384117-01     .838756-05     .495892-05
62  5  5.73824 12.25821   3.5965  2893.8 10433.5  15.576  .45608   .00456  .01000   .03394  1.8826   296.65  3
    1     .328107-01     .103466+05     .160552+02     .295560+04     .495732-02     .107888-05     .209520-05
    2     .651199-01     .103063+05     .162384+02     .298271+04     .974774-02     .213005-05     .292279-05
    3     .112981+00     .102592+05     .164373+02     .301316+04     .192561-01     .420774-05     .379506-05
62  4  5.73593 12.29349   3.5920  2896.6 10425.4  15.528  .45652   .00453  .00995   .07194   .0000     .00  2
    1     .324022-01     .103387+05     .160040+02     .295865+04     .489099-02     .106122-05     .209520-05
    2     .643884-01     .102984+05     .161879+02     .298575+04     .965186-02     .210073-05     .292279-05
    3     .111677+00     .102518+05     .163870+02     .301614+04     .190506-01     .413351-05     .379506-05
    4     .201562+00     .101809+05     .166889+02     .306200+04     .385198-01     .831445-05     .495892-05
*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=     -.94279     MASS FLOW DECREMENTS=     -.01032
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -1.66426     MASS FLOW DECREMENTS=     -.01820
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=    -2.13804     MASS FLOW DECREMENTS=     -.02340

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  12.329 :

    VELOCITY = 10291.52 FT/SEC. MASS FLUX =   .822 LBM/SEC*FT**2.  PARTICLE DIAM. = 2.009 MICRONS. IMPACT ANGLE =  .711 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

           1.880 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF       7.519 MILS AT Z/RT =  12.450

 62  5  5.75807 12.32936  3.6026  2388.5 10441.5  15.576  .45525   .00451  .00990   .03399  1.8836   296.79  2
    1     .317147-01     .103526+05     .160188+02     .295168+04     .494553-02     .106964-05     .209520-05
    2     .634857-01     .103122+05     .162019+02     .297883+04     .975332-02     .211165-05     .292279-05
    3     .110614+00     .102652+05     .164000+02     .300930+04     .192763-01     .416915-05     .379506-05
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       1     .308167-01     .103737+05     .158522+02     .293698+04     .488608-02     .102139-05     .209520-05
       2     .617072-01     .103331+05     .160350+02     .296428+04     .965793-02     .201891-05     .292279-05
       3     .107188+00     .102864+05     .162301+02     .299485+04     .189916-01     .397005-05     .379506-05
       4     .193478+00     .102156+05     .165234+02     .304059+04     .382688-01     .799974-05     .495892-05

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PARTICLE IMPACT, WALL (R,Z)=  5.84781 12.65336      AREA RATIO=   34.197
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 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  12.653 :

   VELOCITY = 10263.90 FT/SEC, MASS FLUX =  1.678 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.546 MICRONS, IMPACT ANGLE =  .907 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

        8.620 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      34.480 MILS AT Z/RT =  13.194

 63  5  5.84781 12.65336  3.6234  2870.3 10468.9  15.429  .45238  .00432  .00955  .07212  1.8882  297.51  2
       1     .305130-01     .103792+05     .158588+02     .293422+04     .492729-02     .102848-05     .209520-05
       2     .612923-01     .103385+05     .160411+02     .296154+04     .972253-02     .202935-05     .292279-05
       3     .106669+00     .102918+05     .162358+02     .299212+04     .191409-01     .399529-05     .379506-05
       4     .194962+00     .102156+05     .165234+02     .304059+04     .383257-01     .799974-05     .495892-05
 63  5  5.90315 12.85505  3.6341  2861.0 10482.5  15.285  .45090  .00425  .00937  .07177  1.8909  297.94  3
       1     .310660-01     .103953+05     .157624+02     .292363+04     .490704-02     .100497-05     .209520-05
       2     .617343-01     .103544+05     .159444+02     .295106+04     .965017-02     .198251-05     .292279-05
       3     .106579+00     .103078+05     .161372+02     .298172+04     .190498-01     .390142-05     .379506-05
       4     .193067+00     .102326+05     .164207+02     .302984+04     .381293-01     .780894-05     .495892-05
 63  4  5.08024 11.81082  3.2656  3159.5  9898.9  14.276  .49796  .00458  .00919  .45596  .0000     .00  4
       1     .278184-01     .981845+04     .147957+02     .321813+04     .475311-02     .954315-04     .209520-05
       2     .558939-01     .978153+04     .150182+02     .324348+04     .944339-02     .189601-05     .292279-05
       3     .962626-01     .974004+04     .152453+02     .327701+04     .187061-01     .375574-05     .379506-05
       4     .172060+00     .967379+04     .155614+02     .335170+04     .369618-01     .742108-05     .495892-05
       5     .338816+00     .955267+04     .160429+02     .357022+04     .694217-01     .139359-02     .670406-05
       6     .170390+01     .992688+04     .175324+02     .416700+04     .295675+00     .595656-02     .139242-04
 63  4  5.86981 12.94836  3.6079  2878.2 10438.2  15.111  .45361  .00415  .00914  .14301  .0000     .00  3
       1     .292728-01     .103512+05     .155621+02     .294223+04     .482225-02     .963364-04     .209520-05
       2     .587206-01     .103106+05     .157466+02     .296972+04     .953285-02     .190442-05     .292279-05
       3     .101694+00     .102649+05     .159409+02     .300048+04     .188586-01     .376748-05     .379506-05
       4     .183655+00     .101932+05     .162260+02     .304883+04     .375204-01     .745567-05     .495892-05
       5     .363080+00     .100681+05     .166670+02     .317023+04     .724787-01     .144794-02     .670406-05
 63  5  5.97686 13.12568  3.6494  2847.6 10502.0  15.144  .44879  .00409  .00912  .07146  1.8945  298.51  3
       1     .304143-01     .104159+05     .156292+02     .290994+04     .489396-02     .975450-04     .209520-05
       2     .604963-01     .103749+05     .158129+02     .293745+04     .964945-02     .192330-05     .292279-05
       3     .104221+00     .103284+05     .160046+02     .296818+04     .189804-01     .378312-05     .379506-05
       4     .188013+00     .102541+05     .162838+02     .301603+04     .379375-01     .756159-05     .495892-05
 63  4  5.95747 13.24236  3.6284  2860.9 10466.0  14.958  .45090  .00401  .00890  .14233  .0000     .00  3
       1     .294201-01     .103806+05     .154428+02     .292410+04     .481126-02     .956021-04     .209520-05
       2     .586088-01     .103397+05     .156282+02     .295171+04     .950426-02     .184905-05     .292279-05
       3     .100870+00     .102939+05     .158207+02     .298258+04     .187852-01     .365452-05     .379506-05
       4     .181176+00     .102218+05     .160997+02     .303100+04     .371549-01     .722841-05     .495892-05
       5     .356253+00     .100975+05     .165363+02     .314870+04     .720697-01     .140210-02     .670406-05
*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1       ALFA*THRUST DECREMENTS=    -1.30826      MASS FLOW DECREMENTS=     -.01424
PARTICLE GROUP 2       ALFA*THRUST DECREMENTS=    -2.66283      MASS FLOW DECREMENTS=     -.02896
PARTICLE GROUP 3       ALFA*THRUST DECREMENTS=    -4.66977      MASS FLOW DECREMENTS=     -.05082
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07/26/82  09:49:57 MA      0425AA410     MA              10     300                                     DATE 072682        PAGE   102
PARTICLE GROUP 4        ALFA*THRUST DECREMENTS=     -4.59278       MASS FLOW DECREMENTS=      -.05010
 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  13.397 :
    VELOCITY = 10322.03 FT/SEC, MASS FLUX =  1.548 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.544 MICRONS, IMPACT ANGLE =  .897 DEG.
 CALCULATED EMPIRICAL EROSION RATE:
        8.057 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      32.228 MILS AT Z/RT =  13.909

 63  5  6.05013 13.39705   3.6677  2831.7 10525.3  15.075  .44629   .00394  .00885  .07151  1.8980  299.05  3
       1   .284533-01        .104362+05     .155052+02     .289644+04     .490530-02     .946910-04     .209520-05
       2   .574164-01        .103949+05     .156809+02     .292407+04     .966753-02     .185620-05     .292279-05
       3   .995145-01        .103495+05     .158787+02     .295491+04     .190101-01     .366957-05     .379506-05
       4   .180031+00        .102749+05     .161530+02     .300258+04     .379317-01     .732227-05     .495892-05

IP= 64                           MASS FLOW RATE OF GAS=      167.15
              1--  MASS FLOW RATE OF PARTICLE  1 =    .73896                 2--  MASS FLOW RATE OF PARTICLE  2 =    1.4772
              3--  MASS FLOW RATE OF PARTICLE  3 =    2.9619                 4--  MASS FLOW RATE OF PARTICLE  4 =    5.9908
              5--  MASS FLOW RATE OF PARTICLE  5 =    11.294                 6--  MASS FLOW RATE OF PARTICLE  6 =    52.828
                          TOTAL MASS FLOW RATE =    242.44

                       ENERGY FLOW RATE FOR GAS =    .65653+06
            1-- ENERGY FLOW RATE FOR PARTICLE  1 =    2147.1               2-- ENERGY FLOW RATE FOR PARTICLE  2 =    4343.2
            3-- ENERGY FLOW RATE FOR PARTICLE  3 =    8802.9               4-- ENERGY FLOW RATE FOR PARTICLE  4 =    18017.
            5-- ENERGY FLOW RATE FOR PARTICLE  5 =    34454.               5-- ENERGY FLOW RATE FOR PARTICLE  6 =    .16338+06
                        TOTAL ENERGY FLOW RATE =    .88767+06

LRC ID     R         Z        MACH      TG       VG     THETA-G  TG/TGO   PG/PGO  DG/DGO  SDK/DG   CF       ISP     IT
       K       REK             VPK              THETA-K          TPK      DPK/DG          DPK/DPO            RPK

 64  3   .00000  4.28583   2.2571  4180.8  7870.3    .000  .65891   .01747  .02652 1.20930  .0000      .00  5
       1   .456862-01        .778755+04     .000000        .426094+04     .562674-02     .325065-05     .209520-05
       2   .106256+00        .773231+04     .000000        .429248+04     .120382-01     .697602-05     .292279-05
       3   .210379+00        .765986+04     .000000        .432597+04     .260257-01     .150804-02     .379506-05
       4   .404289+00        .756080+04     .000000        .437101+04     .573579-01     .332352-02     .495892-05
       5   .811610+00        .741069+04     .000000        .443799+04     .125270+00     .725925-02     .670406-05
       6   .409889+01        .675268+04     .000000        .468557+04     .982983+00     .569627-01     .139242-04
 64  4  5.26965 12.41576   3.3184  3109.3  9978.7  14.073  .49003   .00424  .00866  .42820  .0000      .00  3
       1   .257792-01        .989650+04     .145533+02     .317054+04     .476726-02     .902110-04     .209520-05
       2   .522770-01        .985846+04     .147684+02     .319655+04     .947795-02     .179350-05     .292279-05
       3   .903722-01        .981635+04     .149876+02     .322914+04     .187708-01     .355200-05     .379506-05
       4   .161685+00        .975027+04     .152919+02     .329699+04     .370104-01     .700349-05     .495892-05
       5   .319227+00        .962963+04     .157606+02     .349297+04     .691530-01     .130858-02     .670406-05
       6   .161595+01        .900653         .172365+02     .416700+04     .289022+00     .546917-02     .139242-04
 64  4  6.00318 13.39663   3.6406          7 10482.4  14.922  .44928   .00394  .00876  .14219  .0000      .00  2
       1   .285245-01        .103958+05     .153838+02     .291470+04     .480904-02     .920994-04     .209520-05
       2   .572318-01        .103940+05     .155694+02     .294239+04     .949631-02     .181867-05     .292279-05
       3   .987901-01        .103089+05     .157609+02     .297332+04     .187628-01     .359332-05     .379506-05
       4   .177748+00        .102358+05     .160369+02     .302167+04     .371014-01     .710540-05     .495892-05
       5   .349975+00        .101124+05     .164696+02     .313777+04     .720212-01     .137930-02     .670406-05
 64  5  6.08820 13.53904   3.6794  2825.1 10534.9  15.007  .44524   .00388  .00871  .07133  1.8997  299.35  3
       1   .282168-01        .104466+05     .154450+02     .288947+04     .489673-02     .932480-04     .209520-05
       2   .560866-01        .104051+05     .156279+02     .291720+04     .964848-02     .185735-05     .292279-05
       3   .984592-01        .103588+05     .158164+02     .294810+04     .189700-01     .361244-05     .379506-05
       4   .177738+00        .102855+05     .160879+02     .299572+04     .375166-01     .720158-05     .495892-05
 64  4  6.07153 13.62856   3.6586  2835.6 10506.4  14.869  .44690   .00382  .00856  .14210  .0000      .00  2
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          1     .264365-01     .104996+05     .151174+02     .285382+04     .486697-02     .859859-04     .209520-05
          2     .535419-01     .104573+05     .153016+02     .288187+04     .957400-02     .169152-03     .292279-05
          3     .924480-01     .104110+05     .154870+02     .291305+04     .188073-01     .332284-03     .379506-05
          4     .165565+00     .103391+05     .157472+02     .296042+04     .372804-01     .658664-03     .495892-05
   64  4   6.28667 14.36780    3.7102  2793.1 10574.4  14.599  .44020   .00352  .00801   .14082   .0000      .00  2
          1     .262161-01     .104867+05     .150427+02     .285856+04     .479158-02     .835240-04     .209520-05
          2     .530504-01     .104444+05     .152274+02     .288671+04     .943686-02     .165039-03     .292279-05
          3     .915157-01     .103981+05     .154130+02     .291759+04     .185915-01     .325240-03     .379506-05
          4     .163620+00     .103267+05     .156728+02     .296567+04     .366950-01     .641942-03     .495892-05
          5     .321660+00     .102026+05     .160848+02     .307384+04     .715058-01     .124745-02     .670406-05
   64  5   6.32389 14.43170    3.7243  2783.2 10595.8  14.619  .43865   .00351  .00800   .07035  1.9105  301.00  3
          1     .264683-01     .105079+05     .150682+02     .284825+04     .485822-02     .845775-04     .209520-05
          2     .534411-01     .104654+05     .152523+02     .287607+04     .955350-02     .166908-03     .292279-05
          3     .920633-01     .104190+05     .154371+02     .290760+04     .187638-01     .327821-03     .379506-05
          4     .164419+00     .103473+05     .156955+02     .295495+04     .371568-01     .649164-03     .495892-05
   64  4   6.30626 14.43577    3.7149  2789.3 10580.5  14.576  .43961   .00350  .00796   .14075   .0000      .00  2
          1     .261166-01     .104927+05     .150205+02     .285463+04     .479151-02     .833095-04     .209520-05
          2     .528447-01     .104504+05     .152051+02     .288301+04     .943448-02     .164036-03     .292279-05
          3     .911293-01     .104041+05     .153904+02     .291431+04     .185822-01     .323087-03     .379506-05
          4     .162809+00     .103327+05     .156491+02     .296195+04     .366708-01     .637593-03     .495892-05
          5     .319944+00     .102086+05     .160598+02     .306965+04     .712538-01     .123888-02     .670406-05
   64  5   6.34015 14.49408    3.7263  2781.5 10598.2  14.558  .43838   .00349  .00797   .07009  1.9110  301.11  3
          1     .271246-01     .105119+05     .150426+02     .284551+04     .484435-02     .843319-04     .209520-05
          2     .542701-01     .104694+05     .152270+02     .287365+04     .952443-02     .165804-03     .292279-05
          3     .929987-01     .104230+05     .154117+02     .290490+04     .187050-01     .325622-03     .379506-05
          4     .165303+00     .103514+05     .156694+02     .295224+04     .370211-01     .644475-03     .495892-05
   64  4   6.32583 14.50382    3.7190  2786.0 10585.9  14.541  .43908   .00348  .00791   .14055   .0000      .00  2
          1     .262523-01     .104987+05     .149980+02     .285112+04     .478936-02     .828311-04     .209520-05
          2     .529658-01     .104563+05     .151827+02     .287933+04     .942778-02     .163052-03     .292279-05
          3     .911655-01     .104099+05     .153676+02     .291065+04     .185639-01     .321059-03     .379506-05
          4     .162550+00     .103386+05     .156255+02     .295825+04     .366279-01     .633472-03     .495892-05
          5     .318981+00     .102145+05     .160348+02     .306549+04     .711422-01     .123039-02     .670406-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -1.68565      MASS FLOW DECREMENTS=     -.01824
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -3.69126      MASS FLOW DECREMENTS=     -.03995
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=    -7.24885      MASS FLOW DECREMENTS=     -.07847
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -11.24555      MASS FLOW DECREMENTS=     -.12202

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  14.556 :

    VELOCITY = 10401.92 FT/SEC, MASS FLUX =  1.369 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.542 MICRONS, IMPACT ANGLE =  .912 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

      7.850 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       31.402 MILS AT Z/RI =  15.048

   64  5   6.35634 14.55642    3.7307  2777.8 10603.6  14.558  .43780   .00346  .00791   .07014  1.9117  301.22  2
          1     .264389-01     .105159+05     .150168+02     .284279+04     .484988-02     .837851-04     .209520-05
          2     .532830-01     .104734+05     .152016+02     .287095+04     .953349-02     .164704-03     .292279-05
          3     .916301-01     .104269+05     .153862+02     .290222+04     .187211-01     .323432-03     .379506-05
          4     .163248+00     .103554+05     .156433+02     .294955+04     .370337-01     .639806-03     .495892-05

IP= 71                 MASS FLOW RATE OF GAS=    167.37
         1--  MASS FLOW RATE OF PARTICLE  1 =    .73491            2--  MASS FLOW RATE OF PARTICLE  2 =    1.4659
         3--  MASS FLOW RATE OF PARTICLE  3 =    2.9333            4--  MASS FLOW RATE OF PARTICLE  4 =    5.9166
         5--  MASS FLOW RATE OF PARTICLE  5 =    11.288            6--  MASS FLOW RATE OF PARTICLE  6 =    52.825
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07/26/82  09:49:57 MA      0425AA410    MA              10    300                                               DATE 072682          PAGE   106
           4     .159518+00      .103686+05     .155606+02     .294075+04      .365729-01     .624400-05     .495892-05
 65   4  6.40631 14.78480     3.7385  2770.2 10611.3  14.463  .43660     .00337  .00772     .14007   .0000       .00  2
           1     .255094-01      .105233+05     .149066+02     .283602+04      .475137-02     .806626-04     .209520-05
           2     .517196-01      .104805+05     .150916+02     .286433+04      .940071-02     .158592-05     .292279-05
           3     .891425-01      .104339+05     .152757+02     .289574+04      .184886-01     .311906-05     .379506-05
           4     .158808+00      .103628+05     .155300+02     .294318+04      .364541-01     .614980-05     .495892-05
           5     .311564+00      .102388+05     .159335+02     .304868+04      .709433-01     .119683-02     .6704   .05
 65   5  6.42291 14.81359     3.7433  2767.2 10618.9  14.438  .43612     .00337  .00775     .06965  1.9146  301.67  3
           1     .263025-01      .105525+05     .149170+02     .283160+04      .402643-02     .815551-04     .209520-05
           2     .528228-01      .104896+05     .151020+02     .285988+04      .947830-02     .160151-05     .292279-05
           3     .905695-01      .104430+05     .152859+02     .289126+04      .185040-01     .314365-05     .379506-05
           4     .160668+00      .103719+05     .155398+02     .293855+04      .367177-01     .620441-05     .495892-05
 65   4  6.42055 14.83468     3.7406  2768.6 10614.1  14.419  .43634     .00336  .00770     .13969   .0000       .00  2
           1     .259996-01      .105275+05     .148902+02     .283340+04      .477066-02     .803030-04     .209520-05
           2     .523486-01      .104847+05     .150754+02     .286172+04      .937715-02     .157845-05     .292279-05
           3     .898705-01      .104381+05     .152594+02     .289315+04      .184375-01     .310352-05     .379506-05
           4     .159543+00      .103671+05     .155132+02     .294055+04      .363474-01     .611826-05     .495892-05
           5     .312144+00      .102430+05     .159158+02     .304575+04      .707540-01     .119098-02     .670406-05
 65   5  6.43465 14.85919     3.7463  2764.7 10622.6  14.438  .43572     .00335  .00769     .06961  1.9151  301.75  2
           1     .258103-01      .105353+05     .148987+02     .282966+04      .482796-02     .811559-04     .209520-05
           2     .521162-01      .104924+05     .150840+02     .285796+04      .947923-02     .159342-05     .292279-05
           3     .895964-01      .104458+05     .152679+02     .288935+04      .185038-01     .312721-05     .379506-05
           4     .159223+00      .103747+05     .155213+02     .293664+04      .367009-01     .616925-05     .495892-05
 65   4  6.43300 14.87838     3.7439  2766.0 10618.3  14.414  .43593     .00334  .00767     .13970   .0000       .00  2
           1     .257367-01      .105313+05     .148757+02     .283112+04      .477328-02     .799975-04     .209520-05
           2     .519588-01      .104884+05     .150612+02     .285945+04      .937987-02     .157201-05     .292279-05
           3     .893107-01      .104418+05     .152451+02     .289088+04      .184383-01     .309015-05     .379506-05
           4     .158652+00      .103707+05     .154985+02     .293826+04      .363432-01     .609092-05     .495892-05
           5     .310580+00      .102467+05     .159003+02     .304320+04      .707632-01     .118595-02     .670406-05
 65   5  6.44493 14.89913     3.7490  2762.4 10626.0  14.438  .43536     .00333  .00766     .06960  1.9155  301.82  2
           1     .254214-01      .105579+05     .148834+02     .282796+04      .482982-02     .808041-04     .209520-05
           2     .515442-01      .104949+05     .150687+02     .285627+04      .945093-02     .158618-05     .292279-05
           3     .887961-01      .104483+05     .152525+02     .288768+04      .185052-01     .311269-05     .379506-05
           4     .158014+00      .103772+05     .155035+02     .293496+04      .365890-01     .613816-05     .495892-05
 65   4  6.44389 14.91663     3.7471  2763.4 10622.4  14.417  .43552     .00333  .00764     .13979   .0000       .00  2
           1     .253554-01      .105345+05     .148635+02     .282912+04      .477861-02     .797348-04     .209520-05
           2     .514051-01      .104916+05     .150490+02     .285746+04      .939811-02     .156648-05     .292279-05
           3     .885448-01      .104449+05     .152329+02     .288890+04      .184502-01     .307856-05     .379506-05
           4     .157515+00      .103739+05     .154858+02     .293627+04      .365612-01     .606715-05     .495892-05
           5     .308721+00      .102500+05     .158868+02     .304098+04      .705141-01     .118159-02     .670406-05
 65   5  6.45394 14.93410     3.7514  2760.4 10628.9  14.438  .43504     .00332  .00762     .06960  1.9159  301.88  2
           1     .251030-01      .105401+05     .148704+02     .282646+04      .483126-02     .804926-04     .209520-05
           2     .510667-01      .104971+05     .150557+02     .285479+04      .945196-02     .157977-05     .292279-05
           3     .881205-01      .104504+05     .152394+02     .288621+04      .185054-01     .309950-05     .379506-05
           4     .156984+00      .103794+05     .154919+02     .293349+04      .365765-01     .611059-05     .495892-05
 65   4  6.45341 14.95010     3.7499  2761.1 10626.1  14.421  .43517     .00331  .00761     .13988   .0000       .00  2
           1     .250332-01      .105374+05     .148533+02     .282736+04      .478361-02     .795091-04     .209520-05
           2     .509292-01      .104944+05     .150387+02     .285572+04      .939588-02     .156170-05     .292279-05
           3     .878812-01      .104477+05     .152225+02     .288717+04      .184640-01     .306852-05     .379506-05
           4     .156524+00      .103768+05     .154749+02     .293452+04      .363782-01     .604648-05     .495892-05
           5     .307093+00      .102528+05     .158752+02     .303904+04      .705579-01     .117774-02     .670406-05

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PARTICLE IMPACT, WALL (R,Z)=  6.46181 14.96473      AREA RATIO=   41.755
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07/26/82  09:49:57 MA      0425AA410     MA             10     300                                  DATE 072682         PAGE   107
 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  14.965 :

    VELOCITY = 10340.16 FT/SEC. MASS FLUX =  2.620 LBM/SEC*FT**2.  PARTICLE DIAM. = 3.315 MICRONS, IMPACT ANGLE = 1.213 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

        35.212 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF     140.847 MILS AT Z/RT =  16.625

 65  5  6.46181 14.96473  3.7511  2760.6 10628.5  14.380  .43508  .00332  .00765  .13997  1.9162  301.93  3
      1     .260160-01      .105420+05      .148587+02      .282516+04     .481310-02     .802186-04     .209520-05
      2     .522832-01      .104990+05      .150440+02      .285350+04     .944455-02     .157409-03     .292279-05
      3     .896202-01      .104523+05      .152277+02      .288494+04     .185302-01     .308637-03     .379506-05
      4     .158771+00      .103813+05      .154799+02      .293221+04     .365166-01     .608611-03     .495892-05
      5     .312223+00      .102528+05      .158752+02      .303904+04     .705643-01     .117774-02     .670406-05
 65  5  6.51676 15.17930  3.7625  2750.8 10642.1  14.322  .43355  .00324  .00747  .13988  1.9184  302.28  2
      1     .249343-01      .105551+05      .147753+02      .281622+04     .481505-02     .785456-04     .209520-05
      2     .505933-01      .105119+05      .149617+02      .284462+04     .944520-02     .154081-03     .292279-05
      3     .870942-01      .104651+05      .151453+02      .287612+04     .185303-01     .302287-03     .379506-05
      4     .154573+00      .103943+05      .153955+02      .292336+04     .364982-01     .595402-03     .495892-05
      5     .304130+00      .102669+05      .157877+02      .302892+04     .705903-01     .115155-02     .570406-05
 65  4  5.87090 14.40585  3.4782  2962.9 10209.9  13.484  .46696  .00335  .00725  .40510   .0000      .00  3
      1     .221453-01      .101269+05      .139431+02      .302847+04     .476058-02     .754095-04     .209520-05
      2     .452121-01      .100858+05      .141416+02      .305648+04     .945187-02     .150197-03     .292279-05
      3     .780855-01      .100415+05      .143398+02      .308858+04     .187872-01     .297596-03     .379506-05
      4     .138313+00      .997537+04      .146072+02      .314481+04     .369186-01     .584805-03     .495892-05
      5     .271043+00      .985607+04      .150245+02      .329364+04     .680427-01     .107782-02     .670406-05
      6     .137742+01      .924167+04      .164135+02      .416700+04     .267109+00     .423112-02     .139242-04
*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1       ALFA*THRUST DECREMENTS=     -2.06229       MASS FLOW DECREMENTS=     -.02220
PARTICLE GROUP 2       ALFA*THRUST DECREMENTS=     -4.72629       MASS FLOW DECREMENTS=     -.05086
PARTICLE GROUP 3       ALFA*THRUST DECREMENTS=     -9.84018       MASS FLOW DECREMENTS=     -.10599
PARTICLE GROUP 4       ALFA*THRUST DECREMENTS=    -17.81493       MASS FLOW DECREMENTS=     -.19234
PARTICLE GROUP 5       ALFA*THRUST DECREMENTS=    -11.24668       MASS FLOW DECREMENTS=     -.12192
 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  15.820 :

    VELOCITY = 10392.08 FT/SEC. MASS FLUX =  2.416 LBM/SEC*FT**2.  PARTICLE DIAM. = 3.315 MICRONS, IMPACT ANGLE = 1.167 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

        31.027 MILS/SEC. RESULTING IN A MAXIMUM EROSION DEPTH OF     124.106 MILS AT Z/RT =  17.342

 65  5  6.67916 15.82040  3.7935  2724.6 10678.3  14.096  .42942  .00302  .00704  .13905  1.9240  303.28  3
      1     .233217-01      .105928+05      .145429+02      .279033+04     .480686-02     .739715-04     .209520-05
      2     .477203-01      .105490+05      .147302+02      .281896+04     .942175-02     .144988-03     .292279-05
      3     .823747-01      .105019+05      .149130+02      .285066+04     .184750-01     .284355-03     .379506-05
      4     .145879+00      .104317+05      .151574+02      .289783+04     .363587-01     .559512-03     .495892-05
      5     .286107+00      .103059+05      .155385+02      .300069+04     .700139-01     .107742-02     .670406-05
IP= 72                   MASS FLOW RATE OF GAS=    167.65
              1--  MASS FLOW RATE OF PARTICLE  1 =    .73104              2--  MASS FLOW RATE OF PARTICLE  2 =    1.4550
              3--  MASS FLOW RATE OF PARTICLE  3 =   2.9056               4--  MASS FLOW RATE OF PARTICLE  4 =    5.8450
              5--  MASS FLOW RATE OF PARTICLE  5 =   11.185               6--  MASS FLOW RATE OF PARTICLE  6 =    52.821
                         TOTAL MASS FLOW RATE =    242.59

                     ENERGY FLOW RATE FOR GAS =   .65772+06
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          1-- ENERGY FLOW RATE FOR PARTICLE  1 =   2116.1            2-- ENERGY FLOW RATE FOR PARTICLE  2 =   4252.3
          3-- ENERGY FLOW RATE FOR PARTICLE  3 =   8582.6            4-- ENERGY FLOW RATE FOR PARTICLE  4 =   17486.
          5-- ENERGY FLOW RATE FOR PARTICLE  5 =   34000.            6-- ENERGY FLOW RATE FOR PARTICLE  6 =   .16450+06
                         TOTAL ENERGY FLOW RATE =   .88866+06

LRC ID     R         Z        MACH      TG       VG    THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF       ISP   IT
       K        REK            VPK              THETA-K          TPK       DPK/DG          DPK/DPO          RPK

 66  3  .00000  4.97634   2.3690  4028.4  8108.6    .000  .63489  .01176  .01852 1.26291   .0000      .00  5
      1     .382183-01      .501193+04     .000000       .416700+04      .575866-02      .233490-05    .209520-05
      2     .801580-01      .796325+04     .000000       .416700+04      .123659-01      .500496-05    .292279-05
      3     .150490+00      .789842+04     .000000       .419888+04      .267958-01      .108453-02    .379506-05
      4     .290526+00      .779806+04     .000000       .424807+04      .591558-01      .239426-02    .495892-05
      5     .581575+00      .764877+04     .000000       .432016+04      .129720+00      .525028-02    .670406-05
      6     .293123+01      .599270+04     .000000       .458286+04      .102910+01      .416516-01    .139242-04
 66  4 6.08147 15.12657   3.5322  2915.2 10284.7  13.302  .45945  .00314  .00684  .39746   .0000      .00  3
      1     .210930-01      .102015+05     .137545+02    .298230+04      .474841-02      .709461-04    .209520-05
      2     .432585-01      .101595+05     .139519+02    .301088+04      .945795-02      .141311-05    .292279-05
      3     .747984-01      .101143+05     .141470+02    .304318+04      .187430-01      .280039-05    .379506-05
      4     .132117+00      .100490+05     .144057+02    .309738+04      .365103-01      .549955-05    .495892-05
      5     .257794+00      .992945+04     .148071+02    .323542+04      .675706-01      .100957-02    .670406-05
      6     .130756+01      .931782+04     .161588+02    .416700+04      .260129+00      .388650-02    .139242-04
 66  5 6.84433 16.48299   3.8243  2698.8 10714.0  13.883  .42534  .00285  .00665  .13526  1.9309  304.25  3
      1     .218812-01      .106291+05     .143199+02    .276514+04      .479828-02      .696806-04    .209520-05
      2     .450785-01      .105848+05     .145074+02    .279399+04      .939708-02      .136464-05    .292279-05
      3     .780434-01      .105372+05     .146897+02    .282590+04      .184238-01      .267551-05    .379506-05
      4     .137971+00      .104674+05     .149288+02    .287308+04      .362182-01      .525951-05    .495892-05
      5     .269703+00      .103431+05     .152989+02    .297374+04      .694248-01      .100817-02    .670406-05
 66  4 6.29509 15.86968   3.5567  2868.1 10558.6  13.148  .45203  .00291  .00645  .39052   .0000      .00  3
      1     .198713-01      .102744+05     .135812+02    .293712+04      .473903-02      .667521-04    .209520-05
      2     .410628-01      .102315+05     .137765+02    .296629+04      .943712-02      .132927-05    .292279-05
      3     .712668-01      .101854+05     .139687+02    .299889+04      .187045-01      .263464-05    .379506-05
      4     .125814+00      .101186+05     .142196+02    .305168+04      .367184-01      .517200-05    .495892-05
      5     .244785+00      .100006+05     .146057+02    .318088+04      .671585-01      .945968-05    .670406-05
      6     .124021+01      .939200+04     .159177+02    .416700+04      .255765+00      .357444-02    .139242-04

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -2.42516      MASS FLOW DECREMENTS=     -.02598
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -5.73523      MASS FLOW DECREMENTS=     -.06142
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=   -12.37487      MASS FLOW DECREMENTS=     -.13267
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -24.19225      MASS FLOW DECREMENTS=     -.25999
PARTICLE GROUP 5      ALFA*THRUST DECREMENTS=   -27.40026      MASS FLOW DECREMENTS=     -.29563

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  17.162 :

   VELOCITY = 10463.66 FT/SEC, MASS FLUX =  2.143 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.309 MICRONS, IMPACT ANGLE = 1.126 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

        26.817 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF     107.269 MILS AT Z/RT =  18.525

 66  5 7.01099 17.16206   3.8552  2673.3 10749.2  13.682  .42132  .00264  .00627  .13750  1.9369  305.19  3
      1     .206043-01      .106641+05     .141086+02    .274068+04      .479100-02      .656787-04    .209520-05
      2     .426750-01      .106193+05     .142953+02    .276979+04      .937481-02      .128517-05    .292279-05
      3     .741026-01      .105711+05     .144770+02    .280195+04      .185750-01      .251899-05    .379506-05
      4     .130831+00      .105015+05     .147115+02    .284920+04      .360921-01      .494779-05    .495892-05
      5     .254845+00      .103784+05     .150708+02    .294805+04      .685632-01      .944029-05    .670406-05
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IP= 68                              MASS FLOW RATE OF GAS=   167.92
                 1--  MASS FLOW RATE OF PARTICLE  1 =   .72746                 2--  MASS FLOW RATE OF PARTICLE  2 =   1.4447
                 3--  MASS FLOW RATE OF PARTICLE  3 =   2.8792                 4--  MASS FLOW RATE OF PARTICLE  4 =   5.7769
                 5--  MASS FLOW RATE OF PARTICLE  5 =   11.011                 6--  MASS FLOW RATE OF PARTICLE  6 =   52.818
                               TOTAL MASS FLOW RATE =   242.58

                          ENERGY FLOW RATE FOR GAS =   .65845+06
               1-- ENERGY FLOW RATE FOR PARTICLE  1 =   2105.0               2-- ENERGY FLOW RATE FOR PARTICLE  2 =   4214.8
               3-- ENERGY FLOW RATE FOR PARTICLE  3 =   8452.3               4-- ENERGY FLOW RATE FOR PARTICLE  4 =   17236.
               5-- ENERGY FLOW RATE FOR PARTICLE  5 =   33403.               5-- ENERGY FLOW RATE FOR PARTICLE  6 =   .16497+06
                             TOTAL ENERGY FLOW RATE =   .88886+06

LRC ID    R          Z         MACH      TG        VG      THETA-G  TG/TGO   PG/PGO  DG/DGO   SDK/DG    CF        ISP   IT
      K       REK                VPK               THETA-K            TPK      DPK/JG            DPK/DPO              RPK

 67  3   .00000  5.34944  2.4228  3955.9  8217.9      .000   .62347  .00965  .01555 1.28853   .0000        .00  5
      1     .351161-01    .511525+04    .000000           .416700+04    .584256-02       .198306-05     .203520-05
      2     .709731-01    .506628+04    .000000           .416700+04    .125404-01       .425635-05     .292279-05
      3     .129436+00    .500494+04    .000000           .416700+04    .272061-01       .923405-05     .379506-05
      4     .246997+00    .790689+04    .000000           .419114+04    .600615-01       .203855-02     .495892-05
      5     .494056+00    .775774+04    .000000           .426586+04    .131940+00       .447819-02     .670406-05
      6     .248658+01    .710284+04    .000000           .453582+04    .105094+01       .356699-01     .139242-04
 67  4  6.50687 16.61776  3.6376  2825.3 10126.9  12.982   .44528  .00272  .00610  .38344    .0000        .00  3
      1     .190319-01    .103430+05    .134158+02        .289484+04    .472537-02       .529450-04     .209520-05
      2     .394421-01    .102994+05    .136105+02        .292444+04    .939972-02       .125255-05     .292279-05
      3     .685653-01    .102524+05    .138014+02        .295732+04    .185302-01       .248271-05     .379506-05
      4     .120809+00    .101852+05    .140466+02        .300911+04    .365559-01       .487154-05     .495892-05
      5     .234002+00    .100675+05    .144195+02        .313129+04    .665642-01       .888387-05     .670406-05
      6     .118008+01    .946250+04    .156945+02        .416700+04    .247466+00       .329780-02     .139242-04
 67  5  7.17517 17.84087  3.8849  2649.0 10782.7  13.496   .41749  .00245  .00594  .13672  1.9425    306.08  3
      1     .194877-01    .106973+05    .139130+02        .271742+04    .475254-02       .620317-04     .209520-05
      2     .405298-01    .106519+05    .140984+02        .274683+04    .935017-02       .121276-05     .292279-05
      3     .705887-01    .106031+05    .142794+02        .277927+04    .185223-01       .237638-05     .379506-05
      4     .124526+00    .105333+05    .145100+02        .282666+04    .359623-01       .466447-05     .495892-05
      5     .241717+00    .104112+05    .148591+02        .292404+04    .683045-01       .885941-05     .670406-05
 67  4  6.72073 17.38426  3.6864  2785.6 10492.4  12.845   .43902  .00253  .00576  .37749    .0000        .00  3
      1     .179140-01    .104086+05    .132640+02        .285524+04    .472062-02       .594429-04     .209520-05
      2     .373706-01    .103644+05    .134567+02        .288506+04    .935536-02       .119152-05     .292279-05
      3     .652630-01    .103166+05    .136460+02        .291810+04    .185975-01       .234184-05     .379506-05
      4     .115090+00    .102483+05    .138861+02        .296909+04    .364746-01       .459295-05     .495892-05
      5     .222482+00    .101314+05    .142464+02        .308555+04    .663223-01       .835149-05     .670406-05
      6     .111890+01    .953063+04    .154837+02        .416700+04    .241992+00       .304721-02     .139242-04

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -2.75732      MASS FLOW DECREMENTS=     -.02942
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -6.66955      MASS FLOW DECREMENTS=     -.07113
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=   -14.73843      MASS FLOW DECREMENTS=     -.15735
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -30.12580      MASS FLOW DECREMENTS=     -.32242
PARTICLE GROUP 5      ALFA*THRUST DECREMENTS=   -42.21092      MASS FLOW DECREMENTS=     -.45352

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  18.533 :

    VELOCITY = 10527.69 FT/SEC, MASS FLUX =  1.910 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.305 MICRONS, IMPACT ANGLE = 1.784 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

        22.959 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       91.834 MILS AT Z/RT =  19.750
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 67  5  7.34038 18.55332   3.9142  2625.2 10815.5  13.323  .41575   .00235  .00562   .15595  1.9480   306.94  5
      1      .184146-01     .107294+05      .137284+02      .269478+04     .477372-02      .586374-04     .209520-05
      2      .384672-01     .106835+05      .139118+02      .272452+04     .932441-02      .114535-03     .292279-05
      3      .672419-01     .106340+05      .140918+02      .275728+04     .182674-01      .224356-03     .379506-05
      4      .1187-0+00     .105639+05      .143109+02      .280486+04     .355309-01      .440125-03     .495892-05
      5      .2296.2+00     .104426+05      .146585+02      .290102+04     .677492-01      .832130-03     .670406-05

 IP= 69                    MASS FLOW RATE OF GAS=     168.11
               1--  MASS FLOW RATE OF PARTICLE  1 =   .72428                    2--  MASS FLOW RATE OF PARTICLE  2 =    1.4355
               3--  MASS FLOW RATE OF PARTICLE  3 =   2.8552                    4--  MASS FLOW RATE OF PARTICLE  4 =    5.7155
               5--  MASS FLOW RATE OF PARTICLE  5 =   10.853                    6--  MASS FLOW RATE OF PARTICLE  6 =    52.815
                          TOTAL MASS FLOW RATE =     242.51

                        ENERGY FLOW RATE FOR GAS =   .65896+06
             1-- ENERGY FLOW RATE FOR PARTICLE  1 =  2099.0                   2-- ENERGY FLOW RATE FOR PARTICLE  2 =   4183.6
             3-- ENERGY FLOW RATE FOR PARTICLE  3 =  8394.5                   4-- ENERGY FLOW RATE FOR PARTICLE  4 =   17012.
             5-- ENERGY FLOW RATE FOR PARTICLE  5 =  32562.                   6-- ENERGY FLOW RATE FOR PARTICLE  6 =   .16536+06
                          TOTAL ENERGY FLOW RATE =   .85887+06

 LRC ID     R        Z        MACH     TG      VG     THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF        ISP   IT
        K        REK          VPK            THETA-K            TPK     DPK/DG          DPK/DPO             RPK

 68  3   .00000  5.72260   2.4728  3889.5  8316.6     .000  .61300   .00807  .01317 1.31194   .0000      .00  4
      1      .329958-01     .520199+04      .000000        .416700+04     .591437-02      .170206-05     .209520-05
      2      .643356-01     .515639+04      .000000        .416700+04     .127120-01      .365851-05     .292279-05
      3      .113972+00     .509801+04      .000000        .416700+04     .275115-01      .794615-05     .379506-05
      4      .213462+00     .500326+04      .000000        .416700+04     .609297-01      .175346-02     .495892-05
      5      .425411+00     .785468+04      .000000        .421717+04     .134043+00      .385754-02     .670406-05
      6      .213226+01     .720182+04      .000000        .449379+04     .107073+01      .308159-01     .139242-04
 68  4  6.92008 18.10837   3.7311  2749.8 10551.5  12.733  .43339   .00237  .00547   .37239   .0000      .00  3
      1      .169246-01     .104674+05      .131368+02      .281991+04     .472020-02      .564373-04     .209520-05
      2      .355058-01     .104227+05      .133263+02      .284992+04     .937436-02      .112093-03     .292279-05
      3      .622961-01     .103741+05      .135137+02      .288311+04     .185692-01      .222024-05     .379506-05
      4      .110037+00     .103057+05      .137493+02      .293355+04     .364041-01      .435258-05     .495892-05
      5      .212442+00     .101884+05      .140987+02      .304547+04     .660153-01      .789316-05     .670406-05
      6      .106584+01     .959140+04      .153005+02      .416700+04     .237307+00      .283738-02     .139242-04
 68  5  7.49381 19.18449   3.9419  2603.1 10845.8  13.196  .41023   .00219  .00534   .15544  1.9528   307.70  2
      1      .172658-01     .107583+05      .135718+02      .267422+04     .477166-02      .556907-04     .209520-05
      2      .363150-01     .107119+05      .137514+02      .270436+04     .931320-02      .108696-03     .292279-05
      3      .638463-01     .106616+05      .139296+02      .273746+04     .182430-01      .212917-03     .379506-05
      4      .112941+00     .105911+05      .141531+02      .278529+04     .357649-01      .417419-03     .495892-05
      5      .218435+00     .104703+05      .144841+02      .288054+04     .673458-01      .786004-05     .670406-05
 68  4  7.12184 18.85024   3.7755  2714.9 10608.8  12.630  .42788   .00222  .00520   .36745   .0000      .00  3
      1      .160262-01     .105247+05      .130199+02      .278555+04     .472022-02      .556152-04     .209520-05
      2      .337650-01     .104796+05      .132055+02      .281575+04     .935282-02      .106349-03     .292279-05
      3      .595038-01     .104302+05      .133907+02      .284912+04     .185381-01      .210567-03     .379506-05
      4      .105305+00     .103611+05      .136220+02      .289914+04     .365301-01      .412660-03     .495892-05
      5      .203080+00     .102439+05      .139612+02      .300716+04     .657055-01      .746325-03     .670405-05
      6      .101608+01     .965037+04      .151275+02      .412368+04     .232824+00      .264456-02     .139242-04

 *** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
 PARTICLE GROUP 1        ALFA*THRUST DECREMENTS=     -3.04751        MASS FLOW DECREMENTS=      -.03239
 PARTICLE GROUP 2        ALFA*THRUST DECREMENTS=     -7.48701        MASS FLOW DECREMENTS=      -.07955
 PARTICLE GROUP 3        ALFA*THRUST DECREMENTS=    -16.81630        MASS FLOW DECREMENTS=      -.17889
 PARTICLE GROUP 4        ALFA*THRUST DECREMENTS=    -35.33712        MASS FLOW DECREMENTS=      -.37685
 PARTICLE GROUP 5        ALFA*THRUST DECREMENTS=    -55.04082        MASS FLOW DECREMENTS=      -.56928
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07/26/82  09:49:57 MA      0425AA410    MA              10     300                                          DATE 072682        PAGE   112

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  19.849 :

    VELOCITY = 10582.48 FT/SEC, MASS FLUX =  1.721 LBM/SEC*FT**2,  PARTICLE DIAM. = 5.301 MICRONS, IMPACT ANGLE = 1.046 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

        19.776 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       79.104 MILS AT Z/RT =  20.937

 68  5  7.64847 19.84884  3.9674  2582.8 10873.4  13.029  .40707  .00207  .00509  .13449  1.9576  308.45  3
      1     .167690-01      .107866+05      .134213+02      .265430+04      .475390-02      .529247-04      .209520-05
      2     .351191-01      .107597+05      .135976+02      .268480+04      .927057-02      .105212-03      .292279-05
      3     .617305-01      .106886+05      .137742+02      .271824+04      .181573-01      .202144-03      .379506-05
      4     .109024+00      .106174+05      .139947+02      .276634+04      .355804-01      .396115-03      .495892-05
      5     .209947+00      .104969+05      .143176+02      .286082+04      .667230-01      .742820-03      .670406-05

IP= 72                           MASS FLOW RATE OF GAS=    168.25
              1--  MASS FLOW RATE OF PARTICLE  1 =     .72141                    2--  MASS FLOW RATE OF PARTICLE  2 =    1.4275
              3--  MASS FLOW RATE OF PARTICLE  3 =     2.8341                    4--  MASS FLOW RATE OF PARTICLE  4 =    5.6615
              5--  MASS FLOW RATE OF PARTICLE  5 =     10.718                    6--  MASS FLOW RATE OF PARTICLE  6 =    52.812
                                 TOTAL MASS FLOW RATE =    242.42

                             ENERGY FLOW RATE FOR GAS =    .65935+06
            1-- ENERGY FLOW RATE FOR PARTICLE  1 =     2093.8                    2-- ENERGY FLOW RATE FOR PARTICLE  2 =    4159.2
            3-- ENERGY FLOW RATE FOR PARTICLE  3 =     8320.9                    4-- ENERGY FLOW RATE FOR PARTICLE  4 =    16818.
            5-- ENERGY FLOW RATE FOR PARTICLE  5 =     32393.                    6-- ENERGY FLOW RATE FOR PARTICLE  6 =    .16565+06
                               TOTAL ENERGY FLOW RATE =    .88878+06

LRC ID      R          Z       MACH      TG       VG      THETA-G  TG/TGO   PG/PGO  DG/DGO  SDK/DG    CF       ISP    IT
        K       REK            VPK              THETA-K            TPK           DPK/DG          DPK/DPD          RPK

 69  3   .00000  6.07290  2.5141  3834.8  8396.0     .000  .60438  .00691  .01143 1.32628   .0000      .00  4
      1     .299810-01      .927720+04      .000000         .416700+04      .595439-02      .148784-03      .209520-05
      2     .580708-01      .923103+04      .000000         .416700+04      .125168-01      .320257-03      .292279-05
      3     .101239+00      .917449+04      .000000         .[illegible]6700+04      .275698-01      .696358-03      .379506-05
      4     .186949+00      .908295+04      .000000         .416700+04      .614545-01      .153558-02      .495892-05
      5     .371840+00      .793542+04      .000000         .417614+04      .135334+00      .338161-02      .670406-05
      6     .186160+01      .728574+04      .000000         .445844+04      .105281+01      .270555-01      .139242-04
 69  4  7.29834 19.50633  3.8130  2685.9 10656.7  12.552  .42331  .00211  .00498  .36344   .0000      .00  3
      1     .152089-01      .105729+05      .129273+02      .275673+04      .471910-02      .513043-04      .209520-05
      2     .321992-01      .105275+05      .131050+02      .278710+04      .934932-02      .101642-03      .292279-05
      3     .570171-01      .104774+05      .132918+02      .282061+04      .185032-01      .201160-03      .379506-05
      4     .101185+00      .104077+05      .135196+02      .287037+04      .362530-01      .394150-03      .495892-05
      5     .195137+00      .102903+05      .138503+02      .297548+04      .654250-01      .711277-03      .670406-05
      6     .974772+00      .969987+04      .149861+02      .406158+04      .229188+00      .249165-02      .139242-04
 69  5  7.78324 20.43416  3.9895  2565.5 10697.1  12.907  .40433  .00195  .00489  .13372  1.9615  309.07  3
      1     .160808-01      .108102+05      .132927+02      .263756+04      .474065-02      .506679-04      .209520-05
      2     .337681-01      .107630+05      .134674+02      .266834+04      .923791-02      .987330-04      .292279-05
      3     .595379-01      .107112+05      .136431+02      .270207+04      .180911-01      .193356-03      .379506-05
      4     .105283+00      .106395+05      .138617+02      .275041+04      .354375-01      .378752-03      .495892-05
      5     .202423+00      .105191+05      .141785+02      .284432+04      .662134-01      .707682-03      .670406-05
 69  4  7.47689 20.17650  3.8512  2656.7 10704.8  12.498  .41871  .00199  .00476  .36004   .0000      .00  3
      1     .143401-01      .106203+05      .128462+02      .272845+04      .472150-02      .490674-04      .209520-05
      2     .305407-01      .105745+05      .130223+02      .275902+04      .934422-02      .971022-04      .292279-05
      3     .543971-01      .105237+05      .132017+02      .279273+04      .184855-01      .192106-03      .379506-05
      4     .969221-01      .104532+05      .134253+02      .284232+04      .362163-01      .376348-03      .495892-05
      5     .187130+00      .103357+05      .137477+02      .294493+04      .652444-01      .677999-03      .670406-05
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      6    .934255+00   .374804+04   .148524+02   .400264+04   .225030+00   .234883-02   .1392*2-04

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ...-
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -3.29549      MASS FLOW DECREMENTS=     -.03492
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -8.17876      MASS FLOW DECREMENTS=     -.08665
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=   -18.57248      MASS FLOW DECREMENTS=     -.19699
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -39.72607      MASS FLOW DECREMENTS=     -.42243
PARTICLE GROUP 5      ALFA*THRUST DECREMENTS=   -65.68580      MASS FLOW DECREMENTS=     -.70123

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  21.031 :

   VELOCITY = 10626.88 FT/SEC, MASS FLUX    1.576 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.298 MICRONS, IMPACT ANGLE = 1.020 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

      17.591 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      70.363 MILS AT Z/RI =  22.023

 69   5  7.91917 21.03061  4.0115  2548.2 10920.5  12.707  .40161  .00189  .00470  .13298  1.9654  309.69  3
      1    .154802-01    .108534+05    .131693+02    .262115+04    .472852-02    .485279-04    .209520-05
      2    .325440-01    .107859+05    .133411+02    .265222+04    .920683-02    .944879-04    .292279-05
      3    .575194-01    .107534+05    .135160+02    .268624+04    .180282-01    .185020-03    .379506-05
      4    .101827+00    .106609+05    .137328+02    .273484+04    .353015-01    .362292-03    .495892-05
      5    .195454+00    .105406+05    .140439+02    .282826+04    .657159-01    .674450-03    .670406-05

IP= 75                        MASS FLOW RATE OF GAS=    168.34
          1--  MASS FLOW RATE OF PARTICLE  1 =    .71884              2--  MASS FLOW RATE OF PARTICLE  2 =    1.4202
          3--  MASS FLOW RATE OF PARTICLE  3 =    2.8159              4--  MASS FLOW RATE OF PARTICLE  4 =    5.6157
          5--  MASS FLOW RATE OF PARTICLE  5 =    10.606              6--  MASS FLOW RATE OF PARTICLE  6 =    52.811
                        TOTAL MASS FLOW RATE =    242.33

                     ENERGY FLOW RATE FOR GAS =    .65963+06
        1-- ENERGY FLOW RATE FOR PARTICLE  1 =    2059.6           2-- ENERGY FLOW RATE FOR PARTICLE  2 =    4139.8
        3-- ENERGY FLOW RATE FOR PARTICLE  3 =    8260.7           4-- ENERGY FLOW RATE FOR PARTICLE  4 =    16657.
        5-- ENERGY FLOW RATE FOR PARTICLE  5 =    32006.           5-- ENERGY FLOW RATE FOR PARTICLE  6 =    .16586+06
                       TOTAL ENERGY FLOW RATE =    .88864+06

LRC ID     R         Z        MACH     TG      VG     THETA-G  TG/TGO   PG/PGU  DG/DGO  SDK/DG    CF      ISP   IT
      K        REK             VPK            THETA-K          TPK       DPK/DG        DPK/DPO           RPK

 70   3   .00000  6.40911  2.5479  3790.2  8459.3    .000   .59735  .00605  .01012 1.33065  .0000     .00  4
      1    .266282-01    .534101+04    .000000       .416700+04    .596776-02    .131972-03    .209520-05
      2    .519312-01    .529594+04    .000000       .416700+04    .128537-01    .284391-03    .292279-05
      3    .899539-01    .523872+04    .000000       .416700+04    .279729-01    .615907-03    .379506-05
      4    .164710+00    .515021+04    .000000       .416700+04    .616129-01    .136320-02    .495892-05
      5    .327880+00    .500419+04    .000000       .416700+04    .135746+00    .300342-02    .670406-05
      6    .164645+01    .735904+04    .000000       .442774+04    .103648+01    .240386-01    .139242-04
 70   4  7.63429 20.77236  3.8827  2633.0 10744.0  12.423  .41497  .00190  .00459  .35506  .0000      .00  2
      1    .139143-01    .106607+05    .127776+02    .270422+04    .470795-02    .472070-04    .209520-05
      2    .296004-01    .106247+05    .129497+02    .273498+04    .930632-02    .935152-04    .292279-05
      3    .528074-01    .105633+05    .131266+02    .276886+04    .184048-01    .184547-03    .379506-05
      4    .941937-01    .104921+05    .133471+02    .281839+04    .360538-01    .361514-03    .495892-05
      5    .181691+00    .103743+05    .136628+02    .291909+04    .643649-01    .650406-03    .670406-05
      6    .904116+00    .378897+04    .147417+02    .395363+04    .222720+00    .223323-02    .139242-04
 70   5  8.03843 21.55988  4.0293  2534.5 10939.1  12.670  .39944  .00182  .00454  .15206  1.9688  310.21  3
      1    .151183-01    .109529+05    .130615+02    .260722+04    .470821-02    .467584-04    .209520-05
      2    .317186-01    .108052+05    .132331+02    .263852+04    .915029-02    .909751-04    .292279-05
      3    .560942-01    .107522+05    .134074+02    .267279+04    .179356-01    .178122-03    .379506-05
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         4    .993143-01     .106791+05     .136231+02     .272161+04     .351092-01     .348678-05     .335892-05
         5    .190245+00     .105586+05     .139299+02     .281467+04     .651468-01     .645959-05     .670406-05
  70   4  7.79351 21.37981   3.9150  2608.8 10783.7  12.354  .41116  .00182  .00442   .35255   .0000      .00  2
         1    .135126-01     .107004+05     .127091+02     .268045+04     .469768-02     .454120-04     .209520-05
         2    .287131-01     .106542+05     .128784+02     .271137+04     .927551-02     .896555-04     .292279-05
         3    .512974-01     .106022+05     .130532+02     .274543+04     .185376-01     .177268-05     .379506-05
         4    .915992-01     .105504+05     .132712+02     .279493+04     .359205-01     .347240-05     .495892-05
         5    .176518+00     .104122+05     .135809+02     .289393+04     .645622-01     .624116-05     .670406-05
         6    .875047+00     .982901+04     .146351+02     .390657+04     .219737+00     .212417-02     .139242-04

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1       ALFA*THRUST DECREMENTS=     -3.51122        MASS FLOW DECREMENTS=      -.03711
PARTICLE GROUP 2       ALFA*THRUST DECREMENTS=     -8.77584        MASS FLOW DECREMENTS=      -.09273
PARTICLE GROUP 3       ALFA*THRUST DECREMENTS=    -20.08581        MASS FLOW DECREMENTS=      -.21251
PARTICLE GROUP 4       ALFA*THRUST DECREMENTS=    -43.49656        MASS FLOW DECREMENTS=      -.46139
PARTICLE GROUP 5       ALFA*THRUST DECREMENTS=    -74.71001        MASS FLOW DECREMENTS=      -.79568

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.096 :

    VELOCITY = 10663.46 FT/SEC, MASS FLUX =  1.460 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.295 MICRONS, IMPACT ANGLE = 1.029 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

      17.103 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       25.265 MILS AT Z/RT =  22.422

  70   5  8.15872 22.09635   4.0474  2520.5 10958.1  12.556  .39724  .00175  .00440  .13127  1.9720  310.72  3
         1    .147880-01     .108719+05     .129541+02     .259358+04     .469292-02     .459729-04     .209520-05
         2    .309533-01     .108242+05     .131253+02     .262510+04     .912509-02     .876222-04     .292279-05
         3    .547537-01     .107706+05     .132996+02     .265961+04     .178605-01     .171540-05     .379506-05
         4    .969438-01     .106969+05     .135146+02     .270866+04     .349506-01     .335651-05     .495892-05
         5    .185319+00     .105763+05     .138177+02     .280138+04     .645598-01     .620850-05     .570406-05

 IP= 77                  MASS FLOW RATE OF GAS:     168.40
            1--  MASS FLOW RATE OF PARTICLE  1 =    .71660                2--  MASS FLOW RATE OF PARTICLE  2 =    1.4140
            3--  MASS FLOW RATE OF PARTICLE  3 =    2.8003                4--  MASS FLOW RATE OF PARTICLE  4 =    5.5765
            5--  MASS FLOW RATE OF PARTICLE  5 =    10.512                6--  MASS FLOW RATE OF PARTICLE  6 =    52.809
                        TOTAL MASS FLOW RATE =    242.23

                   ENERGY FLOW RATE FOR GAS =     .65989+06
        1-- ENERGY FLOW RATE FOR PARTICLE  1 =    2086.3              2-- ENERGY FLOW RATE FOR PARTICLE  2 =    4124.3
        3-- ENERGY FLOW RATE FOR PARTICLE  3 =    8211.2              4-- ENERGY FLOW RATE FOR PARTICLE  4 =    16520.
        5-- ENERGY FLOW RATE FOR PARTICLE  5 =    31678.              6-- ENERGY FLOW RATE FOR PARTICLE  6 =    .16602+06
                      TOTAL ENERGY FLOW RATE =    .88853+06

 LRC ID    R        Z       MACH      TG      VG    THETA-G  TG/TGO  PG/PGO  DG/DGO  SDK/DG    CF      ISP    IT
        K       REK          VPK            THETA-K          TPK          DPK/DG          DPK/DPO         RPK

  71   3  .00000  6.69195   2.5704  3760.2  8500.1   .000  .59263  .00549  .00926  1.32275   .0000      .00  4
         1    .232655-01     .938775+04     .000000        .416700+04     .595361-02     .120150-05     .209520-05
         2    .462115-01     .534014+04     .000000        .416700+04     .127926-01     .258995-05     .292279-05
         3    .803544-01     .528591+04     .000000        .416700+04     .275504-01     .563852-05     .379506-05
         4    .147148+00     .519994+04     .000000        .416700+04     .612692-01     .124044-02     .495892-05
         5    .294414+00     .505589+04     .000000        .416700+04     .134992+00     .273252-02     .670406-05
         6    .149316+01     .741548+04     .000000        .440416+04     .107993+01     .218640-01     .139242-04
  71   4  8.04617 22.35291   3.9650  2571.8 10843.7  12.234  .40533  .00170  .00419   .34565   .0000      .00  3
         1    .130252-01     .107612+05     .125986+02     .264407+04     .465992-02     .427816-04     .209520-05
         2    .275885-01     .107149+05     .127660+02     .267521+04     .920241-02     .843060-04     .292279-05
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       3    .493350-01    .106622+05    .125593+02    .270954+04    .181803-01    .166555-05    .379506-05
       4    .881767-01    .105692+05    .131547+02    .275902+04    .356039-01    .326178-05    .495892-05
       5    .169583+00    .104704+05    .134570+02    .285568+04    .639413-01    .585756-05    .670406-05
       6    .834832+00    .989913+04    .144749+02    .383644+04    .214080+00    .195125-02    .139292-04

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -3.55337      MASS FLOW DECREMENTS=     -.03754
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -8.89245      MASS FLOW DECREMENTS=     -.09392
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=   -20.39156      MASS FLOW DECREMENTS=     -.21553
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -44.23307      MASS FLOW DECREMENTS=     -.46898
PARTICLE GROUP 5      ALFA*THRUST DECREMENTS=   -76.45125      MASS FLOW DECREMENTS=     -.81396

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.310 :

   VELOCITY = 10670.44 FT/SEC, MASS FLUX =  1.439 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.024 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

       16.717 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      7.935 MILS AT Z/RT =  22.422

 71   5  8.20633 22.31036  4.0545  2512.1 10965.4  12.519  .39638  .00172  .00434  .13095  1.9735  310.92  2
       1    .145485-01    .108793+05    .129122+02    .258030+04    .468726-02    .444372-04    .209520-05
       2    .305102-01    .108314+05    .130834+02    .261991+04    .110997-02    .863662-04    .292279-05
       3    .540565-01    .107777+05    .132576+02    .265450+04    .178340-01    .169075-05    .37950[illegible]-05
       4    .958095-01    .107038+05    .134725+02    .270364+04    .345936-01    .330805-05    .495892-05
       5    .183117+00    .105831+05    .137743+02    .279625+04    .644590-01    .611098-05    .670406-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -3.56888      MASS FLOW DECREMENTS=     -.03769
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -8.93553      MASS FLOW DECREMENTS=     -.09436
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=   -20.49107      MASS FLOW DECREMENTS=     -.21665
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -44.50622      MASS FLOW DECREMENTS=     -.47180
PARTICLE GROUP 5      ALFA*THRUST DECREMENTS=   -77.11076      MASS FLOW DECREMENTS=     -.82074

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.391 :

   VELOCITY = 10673.04 FT/SEC, MASS FLUX =  1.452 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.008 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

       16.021 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      2.196 MILS AT Z/RT =  22.422

 71   .  8.22415 22.39066  4.0578  2512.6 10968.8  12.519  .39599  .00173  .00431  .15102  1.9738  311.00  2
       1    .143021-01    .108821+05    .128970+02    .258633+04    .469003-02    .442014-04    .209520-05
       2    .301319-01    .108392+05    .130680+02    .261797+04    .911465-02    .859014-04    .292279-05
       3    .535249-01    .107804+05    .132422+02    .265260+04    .175429-01    .166161-05    .379506-05
       4    .950399-01    .107063+05    .134570+02    .270178+04    .349093-01    .329004-05    .495892-05
       5    .181906+00    .105856+05    .137583+02    .279434+04    .644594-01    .607500-05    .670406-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -3.57218      MASS FLOW DECREMENTS=     -.03775
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -8.94478      MASS FLOW DECREMENTS=     -.09443
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=   -20.51469      MASS FLOW DECREMENTS=     -.21689
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -44.56529      MASS FLOW DECREMENTS=     -.47241
PARTICLE GROUP 5      ALFA*THRUST DECREMENTS=   -77.25151      MASS FLOW DECREMENTS=     -.82221

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.405 :
```

```
   VELOCITY = 10673.61 FT/SEC, MASS FLUX =  1.430 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.005 DEG.
 CALCULATED EMPIRICAL EROSION RATE:
          15.874 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .964 MILS AT Z/RT =  22.422

 71  5  8.22806 22.40823  4.0565  2512.0 10969.6  12.519  .39590  .00171  .00431  .15102  1.9739  311.02  2
        1    .142501-01     .108827+05    .128937+02    .258590+04    .469052-02    .441499-04    .209520-05
        2    .300506-01     .108538+05    .130647+02    .261754+04    .911567-02    .858000-04    .292279-05
        3    .534097-01     .107810+05    .132389+02    .265218+04    .175449-01    .167955-03    .379506-05
        4    .948718-01     .107069+03    .134536+02    .270137+04    .349128-01    .328612-03    .495892-05
        5    .181629+00     .105861+05    .137549+02    .279392+04    .644595-01    .606717-05    .670406-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -3.57377      MASS FLOW DECREMENTS=     -.03774
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -8.94924      MASS FLOW DECREMENTS=     -.09450
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=   -20.52609      MASS FLOW DECREMENTS=     -.21701
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -44.59382      MASS FLOW DECREMENTS=     -.47270
PARTICLE GROUP 5      ALFA*THRUST DECREMENTS=   -77.31951      MASS FLOW DECREMENTS=     -.82291

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.417 :

   VELOCITY = 10673.89 FT/SEC, MASS FLUX =  1.429 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.003 DEG.

 CALCULATED EMPIRICAL EROSION RATE:
          15.803 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .369 MILS AT Z/RT =  22.422

 71  5  8.22995 22.41675  4.0589  2511.7 10969.9  12.519  .39586  .00170  .00430  .15103  1.9739  311.02  2
        1    .142253-01     .108830+05    .128922+02    .258569+04    .469091-02    .441299-04    .209520-05
        2    .300119-01     .108551+05    .130631+02    .261734+04    .911616-02    .857510-04    .292279-05
        3    .533546-01     .107817+05    .132373+02    .265198+04    .175458-01    .167867-03    .379506-05
        4    .947914-01     .107072+05    .134520+02    .270117+04    .349144-01    .328424-05    .495892-05
        5    .181496+00     .105864+05    .137532+02    .279372+04    .644396-01    .606338-05    .670406-05

*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1      ALFA*THRUST DECREMENTS=    -3.57455      MASS FLOW DECREMENTS=     -.03775
PARTICLE GROUP 2      ALFA*THRUST DECREMENTS=    -8.95143      MASS FLOW DECREMENTS=     -.09452
PARTICLE GROUP 3      ALFA*THRUST DECREMENTS=   -20.53169      MASS FLOW DECREMENTS=     -.21707
PARTICLE GROUP 4      ALFA*THRUST DECREMENTS=   -44.60784      MASS FLOW DECREMENTS=     -.47254
PARTICLE GROUP 5      ALFA*THRUST DECREMENTS=   -77.35294      MASS FLOW DECREMENTS=     -.82326

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.421 :

   VELOCITY = 10674.03 FT/SEC, MASS FLUX =  1.429 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGL. = 1.002 DEG.

 CALCULATED EMPIRICAL EROSION RATE:
          15.768 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .078 MILS AT Z/RT =  22.422

 71  5  8.23088 22.42094  4.0570  2511.6 10970.1  12.519  .39584  .00170  .00430  .15105  1.9739  311.05  1
        1    .142128-01     .108831+05    .128914+02    .258558+04    .469108-02    .441127-04    .209520-05
        2    .299919-01     .108557+05    .130623+02    .261723+04    .911647-02    .857260-04    .292279-05
        3    .533252-01     .107814+05    .132365+02    .265188+04    .175464-01    .167817-03    .379506-05
        4    .947475-01     .107077+05    .134512+02    .270107+04    .349155-01    .328325-05    .495892-05
        5    .181422+00     .105865+05    .137524+02    .279362+04    .644601-01    .606151-05    .670406-05
```

```
*** THRUST AND MASS FLOW DECREMENTS INTEGRATED FROM POINT OF IMPINGEMENT ....
PARTICLE GROUP 1     ALFA*THRUST DECREMENTS=   -3.57475     MASS FLOW DECREMENTS=    -.03775
PARTICLE GROUP 2     ALFA*THRUST DECREMENTS=   -8.95197     MASS FLOW DECREMENTS=    -.09452
PARTICLE GROUP 3     ALFA*THRUST DECREMENTS=  -20.53308     MASS FLOW DECREMENTS=    -.21708
PARTICLE GROUP 4     ALFA*THRUST DECREMENTS=  -44.61132     MASS FLOW DECREMENTS=    -.47283
PARTICLE GROUP 5     ALFA*THRUST DECREMENTS=  -77.36124     MASS FLOW DECREMENTS=    -.52335

 MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.422 :

    VELOCITY = 10674.06 FT/SEC, MASS FLUX =  1.429 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.

 CALCULATED EMPIRICAL EROSION RATE:

        15.759 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       .005 MILS AT Z/RT =  22.422

 71  5  8.23111 22.42198  4.0591  2511.6 10970.2  12.519  .39584  .00170  .00430  .13103  1.9740  311.05  1
       1     .142105-01    .108831+05    .128912+02    .258556+04    .469113-02    .441096-04    .209520-05
       2     .299886-01    .108353+05    .130621+02    .261721+04    .911654-02    .857209-04    .292279-05
       3     .533209-01    .107814+05    .132363+02    .265186+04    .175466-01    .167807-03    .379506-05
       4     .947418-01    .107073+05    .134510+02    .270105+04    .349158-01    .328305-03    .495892-05
       5     .181413+00    .105865+05    .137522+02    .279359+04    .644602-01    .606105-03    .670406-05

IP= 82


                                   PARTICLE IMPINGEMENT SUMMARY

                                      ISP=(F-ALFA*DF)/MDOT

               GROUP D(MICRONS)  ALFA*THRUST  MASS FLOW  SPECIFIC IMPULSE  FIRST IMPINGEMENT
                                 DECREMENTS   DECREMENTS  DECREMENTS         AREA RATIO

                 1     1.277        -3.575      -.038       -.015             25.421

                 2     1.782        -8.952      -.095       -.037             27.921

                 3     2.313       -20.533      -.217       -.085             30.468

                 4     3.023       -44.611      -.473       -.186             34.197

                 5     4.087       -77.361      -.525       -.322             41.755

                 -     5.488          .000       .000        .000               .000

                    TOTALS  -155.032    -1.646       -.645

                    TOTAL THRUST,F=          74724.758
                    TOTAL MASS FLOW,MDOT=      240.251


                                  PARTICLE IMPACT EROSION SUMMARY
                                     FROM EMPIRICAL RELATIONS

                                    Z/RT       EROSION DEPTH (MILS)
```

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9.8729	.00
9.8823	.12
10.4353	.24
10.7190	1.66
11.3736	1.63
11.6455	8.03
12.4797	7.52
13.1945	34.48
13.9093	32.23
15.0482	31.40
16.6255	140.85
17.3424	124.11
18.5287	107.27
19.7504	91.83
21.9365	79.10
22.0234	70.36
22.4221	23.27

PARTICLE IMPACT EROSION MODEL

INPUT DATA

TOTAL EROSION TIME(SEC)= 4.00
PARTICLE DENSITY(LBM/FT**3)= 186.00 TARGET DENSITY(LBM/FT**3)= 120.00 TARGET SHEAR YIELD STRESS(PSI)= 2200.00
FINITE ELEMENT AXIAL LENGTH(MICRONS)= 250. AXIAL PRINT INCREMENT = 2.55 LAST AXIAL PRINT LOCATION(IN)= 50.94
GAS VELOCITY(FPS) = 10197.63 DRAG COEFFICIENT = 5. GAS DENSITY(LB/FT**3) = .00316470

FACTOR= .6782+01 EXPFAC= 2.000

AXIAL LENGTH (IN)	PARTICLE DIAMETER (MICRONS)	PARTICLE VELOCITY (FPS)	INCIDENT FLUX DENSITY (LBM/CU.FT.)	IMPACT ANGLE (DEG)
.006	.12776+01	10109.92	.16122-04	.484
2.152	.12776+01	10172.40	.14857-04	.439
3.123	.16101+01	10171.62	.42082-04	.568
5.667	.16117+01	10237.34	.38973-04	.571
6.262	.20101+01	10216.36	.88765-04	.715
9.534	.20092+01	10291.52	.79853-04	.711
10.791	[illegible]456+01	10263.90	.16353-03	.907
13.677	[illegible]45+01	10322.05	.14997-03	.597
18.177	[illegible]19+01	10401.92	.13164-03	.912
19.762	[illegible]152+01	10340.16	.25341-03	1.215
23.082	.33120+01	10392.08	.23249-03	1.167
28.289	.33086+01	10463.66	.20476-03	1.126
33.611	.33045+01	10527.69	.18140-03	1.084
38.717	.33009+01	10582.48	.16264-03	1.046
43.303	.32976+01	10626.88	.14826-03	1.020
47.439	.32947+01	10663.46	.13695-03	1.029
48.270	.32942+01	10670.44	.13489-03	1.024
48.582	.32940+01	10673.04	.13413-03	1.008
48.650	.32939+01	10673.61	.13397-03	1.00[illegible]
48.683	.32939+01	10673.89	.13389-03	1.00[illegible]
48.699	.32939+01	10674.03	.13385-03	1.002
48.703	.32939+01	10674.06	.13384-03	1.002

CALCULATED AXIAL DISTRIBUTION OF EROSION RATES

AXIAL LENGTH (IN)	% OF PARTICLES PENETRATING DEBRIS LAYER	DEBRIS LAYER VELOCITY (FPS)	DEBRIS LAYER DENSITY (LBM/FT**3)	EROSION RATE (MILS/SEC)	AVE.NO.OF PARTICLE COLLISIONS
.00	99.4	10110.	.00001612	2.2	1
2.55	2.0	10018.	.00002598	.1	3

******* ZERO EROSION RATE CALCULATED FOR 100 CONSECUTIVE STEPS *******

PARTICLE IMPACT EROSION SUMMARY
FROM EROSION MODEL

Z/RT	EROSION DEPTH (MILS)
9.8729	.00
10.1248	8.64
10.5168	.56

5.2 CASE 2: PIEROS WITH DATA FROM ISPP

The second sample used illustrates the use of the PIEROS stand-alone erosion code using the particle conditions saved on unit 10 during the execution of Case 1. This option is useful if the run time of the ISPP run is to be minimized by not including the debris layer erosion model calculations in the same run. Also, input parameters for the empirical erosion model and/or the debris layer model can be changed without re-running the ISPP nozzle flow solution. As an example, the erosion characteristics of different candidate nozzle wall materials could be evaluated by changing the target material properties in subsequent PIEROS runs using the same input impacting particle conditions.

The UNIVAC 1108 control cards for Case 2 are listed in Table C-4. Here the conversion of the saved particle conditions from an element in a users file to the unit to be read (specified by IREAD in the $DATAIN namelist) is accomplished with the @DATA and @ADD control cards.

The input for Case 2 is shown in Table C-5 to be very simple, consisting only of the IREAD description in the $DATAIN namelist, and the erosion time period in $ERODIN. Again, as in Case 1, the default values for most of the erosion model input are being utilized. However, in subsequent runs, these default values could be overwritten by including new values in the namelists.

The Case 2 output is presented in Table C-6, covering pages 84 to 93. The first three pages show the particle conditions saved from Case 1 (and described in Section 3.). On page 87, the erosion calculated with the empirical erosion model is given for each input point using the same output format as Case 1, where the erosion results are printed within the nozzle flow solution. The summary of the erosion depths from the empirical model and the debris layer erosion model results follow in the same order and format as Case 1.

@ASG,AX	PIE.	Assign program file for PIEROS stand-alone code
@ASG,AX	SPP.	Assign program file containing data saved from previous ISPP run.
@ASG,T	10.	Assign temporary file for unit 10 (i.e. IREAD)
@DATA,IL	10.	Assign previously saved data file as
@ADD,PD	SPP.DATA10	Unit 10 (i.e. IREAD)
@XQT	PIE.PIEROS	Execute absolute element PIEROS in program file PIE.
DATA		
@FIN		
@@		Remote job entry end of file

Table C-4: UNIVAC 1108 Control Cards for Sample Case 2

9

```
SD001 TEST CASE
$DATAIN
IREAD=10,
$END
$ERODIN
TIME=4.,
$END
```

Table C-5: Input Data for Sample Case 2

DATA,IL 10.
DATA 9R1.1 SL74T9 07/26/82 09:45:18 (-<0)

ADD,PD SPPNEW.10DATA

1.	.323417+00	.224221+02	.186000+05	.339598+06	
2.	.987285+01	.975033+04	.298711+04	.316470-02	1
3.	.964109+04	.304299+04	.253181+08	.161223-04	.209520-05
4.	.104275+02	.982924+04	294485+04	.293913-02	1
5.	.972182+04	.299399+04	.249999+08	.148565-04	.209520-05
6.	.106776+02	.986246+04	.292408+04	.285025-02	2
7.	.975555+04	.297424+04	.248635+08	.143087-04	.209520-05
8.	.970599+04	.299484+04	.250827+08	.277736-04	.292279-05
9.	.113330+02	.994565+04	.287312+04	.263189-02	2
10.	.983814+04	.292547+04	.245247+08	.131344-04	.209520-05
11.	.979017+04	.294592+04	.247423+08	.258389-04	.292279-05
12.	.114863+02	.996383+04	.286356+04	.258428-02	3
13.	.985644+04	.291459+04	.244489+08	.128785-04	.209520-05
14.	.920855+04	.293499+04	.246670+08	.254187-04	.292279-05
15.	.975100+04	.295642+04	.249166+08	.504592-04	.379506-05
16.	.123294+02	.100581+05	.280370+04	.234967-02	3
17.	.995062+04	.285684+04	.240553+08	.116204-04	.209520-05
18.	.990263+04	.287734+04	.242765+08	.229406-04	.292279-05
19.	.984755+04	.289830+04	.245249+08	.452930-04	.379506-05
20.	.126534+02	.100916+05	.278513+04	.226762-02	4
21.	.998418+04	.283630+04	.239130+08	.111732-04	.209520-05
22.	.993599+04	.285681+04	.241356+08	.220465-04	.292279-05
23.	.988136+04	.287750+04	.243849+08	.434042-04	.379506-05
24.	.979376+04	.290539+04	.247799+08	.869080-04	.495892-05
25.	.133970+02	.101631+05	.273744+04	.209714-02	4
26.	.100564+05	.278985+04	.236051+00	.102871-04	.209520-05
27.	.100076+05	.281091+04	.238303+08	.202742-04	.292279-05
28.	.995364+04	.283137+04	.240816+08	.398668-04	.379506-05
29.	.986926+04	.285852+04	.244702+08	.795481-04	.495892-05
30.	.155564+02	.102632+05	.266529+04	.187687-02	4
31.	.101568+05	.272470+04	.231679+08	.910262-05	.209520-05
32.	.101069+05	.274629+04	.233974+08	.178932-04	.292279-05
33.	.100532+05	.276652+04	.236522+08	.351372-04	.379506-05
34.	.997186+04	.279231+04	.240379+08	.695076-04	.495892-05
35.	.149647+02	.102955+05	.263957+04	.181065-02	5
36.	.101895+05	.270334+04	.230247+08	.871482-05	.209520-05
37.	.101391+05	.272513+04	.232552+08	.171007-04	.292279-05
38.	.100853+05	.274535+04	.235114+08	.335516-04	.379506-05
39.	.100047+05	.277077+04	.238966+08	.661186-04	.495892-05
40.	.986176+04	.280459+04	.247673+08	.127948-03	.670406-05
41.	.158204+02	.103568+05	.260075+04	.167180-02	5
42.	.102535+05	.265991+04	.227403+08	.803613-05	.209520-05
43.	.102023+05	.268227+04	.229736+08	.157513-04	.292279-05
44.	.101482+05	.270269+04	.232320+08	.308916-04	.379506-05
45.	.100688+05	.272759+04	.236165+08	.607846-04	.495892-05
46.	.992925+04	.276082+04	.244547+08	.117049-03	.670406-05
47.	.171621+02	.104442+05	.254262+04	.148930-02	5
48.	.103424+05	.259948+04	.223357+08	.713524-05	.209520-05
49.	.102905+05	.262212+04	.225730+08	.139619-04	.292279-05
50.	.102355+05	.264269+04	.228351+08	.273660-04	.379506-05
51.	.101572+05	.266688+04	.232201+08	.537520-04	.495892-05

Table C-6: Output for Sample Case 2

52.	.100214+05	.259851+04	.240257+0[illegible]	.102558-03	.670406-05
53.	.185333+02	.105243+05	.249223+04	.133445-02	5
54.	.104229+05	.254630+04	.219616+08	.637028-03	.209520-05
55.	.103702+05	.256863+04	.222040+08	.124430-04	.292279-05
56.	.103140+05	.258913+04	.224710+08	.243769-04	.379506-05
57.	.102357+05	.261265+04	.228587+08	.478145-04	.495892-05
58.	.101027+05	.264258+04	.236424+08	.904078-04	.670406-05
59.	.198488+02	.105935+05	.245130+04	.120946-02	5
60.	.104920+05	.250367+04	.216318+08	.574966-05	.209520-05
61.	.104387+05	.252493+04	.218803+08	.112128-04	.292279-05
62.	.103812+05	.254491+04	.221529+08	.219606-04	.379506-05
63.	.103023+05	.256764+04	.225448+08	.430331-04	.495892-05
64.	.101709+05	.259586+04	.233148+08	.806988-04	.670406-05
65.	.210306+02	.106497+05	.241707+04	.111494-02	5
66.	.105485+05	.246797+04	.213616+08	.527200-05	.209520-05
67.	.104948+05	.248882+04	.216148+08	.102650-04	.292279-05
68.	.104351+05	.250857+04	.218921+08	.201003-04	.379506-05
69.	.103552+05	.253084+04	.222881+08	.393589-04	.495892-05
70.	.102255+05	.255784+04	.230495+08	.732723-04	.670406-05
71.	.220963+02	.106960+05	.238222+04	.104341-02	5
72.	.105953+05	.243717+04	.211369+08	.489665-05	.209520-05
73.	.105414+05	.245797+04	.213930+08	.951915-05	.292279-05
74.	.104817+05	.247770+04	.216750+08	.186359-04	.379506-05
75.	.104007+05	.249979+04	.220747+08	.364679-04	.495892-05
76.	.102702+05	.252597+04	.228304+08	.674460-04	.670406-05
77.	.223104+02	.107047+05	.237682+04	.102994-02	5
78.	.106042+05	.243106+04	.210939+[illegible]	.482759-05	.209520-05
79.	.105503+05	.245190+04	.213514+08	.938270-05	.292279-05
80.	.104905+05	.247166+04	.216334+08	.183679-04	.379506-05
81.	.104092+05	.249375+04	.220339+08	.359382-04	.495892-05
82.	.102787+05	.251981+04	.227896+08	.663887-04	.670406-05
83.	.223907+02	.107081+05	.237756+04	.102387-02	5
84.	.106075+05	.242886+04	.2[illegible]0778+08	.480197-05	.209520-05
85.	.105536+05	.244969+04	.213356+08	.933220-05	.292279-05
86.	.104937+05	.246944+04	.216179+08	.182688-04	.379506-05
87.	.104124+05	.24915[illegible]+04	.220187+08	.357425-04	.495892-05
88.	.102819+05	.251754+04	.227730+08	.659979-04	.670406-05
89.	.224082+02	.107088+05	.237772+04	.102255-02	5
90.	.106083+05	.242840+04	.210743+08	.479638-05	.209520-05
91.	.105544+05	.244922+04	.213322+08	.932119-05	.292279-05
92.	.104945+05	.246897+04	.216145+08	.182472-04	.379506-05
93.	.104131+05	.249105+04	.220153+08	.356999-04	.495892-05
94.	.102825+05	.251705+04	.227695+08	.659128-04	.670406-05
95.	.224167+02	.107091+05	.237780+04	.102191-02	5
96.	.106086+05	.242818+04	.210726+08	.479367-05	.209520-05
97.	.105547+05	.244900+04	.213305+08	.931586-05	.292279-05
98.	.104948+05	.246874+04	.216129+08	.182368-04	.379506-05
99.	.104134+05	.249082+04	.220137+08	.356793-04	.495892-05
100.	.102829+05	.251681+04	.227679+08	.658716-04	.670406-05
101.	.224209+02	.107093+05	.237784+04	.102150-02	5
102.	.106088+05	.242807+04	.210717+08	.479234-05	.209520-05
103.	.105549+05	.244888+04	.213297+08	.931324-05	.292279-05
104.	.104950+05	.246863+04	.216121+08	.182316-04	.379506-05
105.	.104136+05	.249070+04	.220129+08	.356691-04	.495892-05
106.	.102830+05	.251669+04	.227671+08	.658514-04	.670406-05
107.	.224220+02	.107094+05	.237785+04	.102150-02	5
108.	.106058+05	.242804+04	.210715+08	.479201-05	.209520-05

```
  109.          .105549+05    .244886+04    .213295+08    .931259-05    .292279-05
  110.          .104950+05    .246860+04    .216119+08    .182304-04    .379506-05
  111.          .104136+05    .249068+04    .220127+08    .356666-04    .495892-05
  112.          .102831+05    .251667+04    .227669+08    .658463-04    .670406-05
  113.          .000000
END DATA. ERRORS: NONE. TIME:  1.510 SEC. IMAGE COUNT: 113


 X3T DOUGPIE.ABS
```

PARTICLE IMPACT EROSION IN A NOZZLE EXIT CONE

SD001 TEST CASE

```
MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =   9.873 :
   VELOCITY = 10109.92 FT/SEC, MASS FLUX =   .163 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE =  .484 DEG.
CALCULATED EMPIRICAL EROSION RATE:
        .081 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       .323 MILS AT Z/RT =   9.882

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  10.428 :
   VELOCITY = 10172.40 FT/SEC, MASS FLUX =   .151 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.278 MICRONS, IMPACT ANGLE =  .439 DEG.
CALCULATED EMPIRICAL EROSION RATE:
        .061 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       .244 MILS AT Z/RT =  10.435

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  10.678 :
   VELOCITY = 10171.62 FT/SEC, MASS FLUX =   .428 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.610 MICRONS, IMPACT ANGLE =  .568 DEG.
CALCULATED EMPIRICAL EROSION RATE:
        .415 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      1.658 MILS AT Z/RT =  10.719

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  11.333 :
   VELOCITY = 10237.34 FT/SEC, MASS FLUX =   .399 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.612 MICRONS, IMPACT ANGLE =  .571 DEG.
CALCULATED EMPIRICAL EROSION RATE:
        .408 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      1.633 MILS AT Z/RT =  11.374

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  11.486 :
   VELOCITY = 10216.36 FT/SEC, MASS FLUX =   .907 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.019 MICRONS, IMPACT ANGLE =  .715 DEG.
CALCULATED EMPIRICAL EROSION RATE:
       2.007 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      8.028 MILS AT Z/RT =  11.646

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  12.329 :
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   VELOCITY = 10291.52 FT/SEC, MASS FLUX =   .622 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.009 MICRONS, IMPACT ANGLE =  .711 DEG.
CALCULATED EMPIRICAL EROSION RATE:
       1.880 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       7.520 MILS AT Z/RT =  12.480

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  12.653 :
   VELOCITY = 10263.90 FT/SEC, MASS FLUX =  1.678 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.546 MICRONS, IMPACT ANGLE =  .907 DEG.
CALCULATED EMPIRICAL EROSION RATE:
       8.620 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      34.479 MILS AT Z/RT =  13.195

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  13.397 :
   VELOCITY = 10322.03 FT/SEC, MASS FLUX =  1.548 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.544 MICRONS, IMPACT ANGLE =  .897 DEG.
CALCULATED EMPIRICAL EROSION RATE:
       8.058 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      32.232 MILS AT Z/RT =  13.909

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  14.556 :
   VELOCITY = 10401.[illegible] FT/SEC, MASS FLUX =  1.569 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.542 MICRONS, IMPACT ANGLE =  .912 DEG.
CALCULATED EMPIRICAL EROSION RATE:
       7.852 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      31.407 MILS AT Z/RT =  15.048

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  14.945 :
   VELOCITY = 10340.16 FT/SEC, MASS FLUX =  2.620 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.315 MICRONS, IMPACT ANGLE = 1.213 DEG.
CALCULATED EMPIRICAL EROSION RATE:
      35.210 MILS/SEC, RESULTING IN [illegible]UM EROSION DEPTH OF     140.840 MILS AT Z/RT =  16.625

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  15.820 :
   VELOCITY = 10392.08 FT/SEC, MASS FLUX =  2.416 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.315 MICRONS, IMPACT ANGLE = 1.167 DEG.
CALCULATED EMPIRICAL EROSION RATE:
      31.029 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF     124.118 MILS AT Z/RT =  17.342

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  17.162 :
   VELOCITY = 10463.65 FT/SEC, MASS FLUX =  2.143 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.309 MICRONS, IMPACT ANGLE = 1.126 DEG.
CALCULATED EMPIRICAL EROSION RATE:
```

```
     26.817 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF     107.268 MILS AT Z/RI =  18.529

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  18.533 :
   VELOCITY = 10527.70 FT/SEC, MASS FLUX =  1.910 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.305 MICRONS, IMPACT ANGLE = 1.084 DEG.
CALCULATED EMPIRICAL EROSION RATE:
     22.963 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      91.850 MILS AT Z/RT =  19.751

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  19.849 :
   VELOCITY = 10582.49 FT/SEC, MASS FLUX =  1.721 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.301 MICRONS, IMPACT ANGLE = 1.046 DEG.
CALCULATED EMPIRICAL EROSION RATE:
     19.778 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      79.114 MILS AT Z/RI =  20.937

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  21.031 :
   VELOCITY = 10626.88 FT/SEC, MASS FLUX =  1.576 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.298 MICRONS, IMPACT ANGLE = 1.020 DEG.
CALCULATED EMPIRICAL EROSION RATE:
     17.593 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      70.370 MILS AT Z/RI =  22.023

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.096 :
   VELOCITY = 10663.46 FT/SEC, MASS FLUX =  1.460 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.295 MICRONS, IMPACT ANGLE = 1.029 DEG.
CALCULATED EMPIRICAL EROSION RATE:
     17.102 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      23.272 MILS AT Z/RI =  22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.310 :
   VELOCITY = 10670.44 FT/SEC, MASS FLUX =  1.459 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.024 DEG.
CALCULATED EMPIRICAL EROSION RATE:
     16.716 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       7.936 MILS AT Z/RI =  22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  22.391 :
   VELOCITY = 10673.05 FT/SEC, MASS FLUX =  1.452 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.008 DEG.
CALCULATED EMPIRICAL EROSION RATE:
     16.023 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       2.196 MILS AT Z/RI =  22.422
```

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.406 :

VELOCITY = 10673.60 FT/SEC, MASS FLUX = 1.430 LBM/SEC*FT**2, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.005 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.875 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .969 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.417 :

VELOCITY = 10673.89 FT/SEC, MASS FLUX = 1.429 LBM/SEC*FT**2, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.003 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.801 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .376 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.421 :

VELOCITY = 10674.01 FT/SEC, MASS FLUX = 1.429 LBM/SEC*FT**2, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.767 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .085 MILS AT Z/RT = 22.422

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT = 22.422 :

VELOCITY = 10674.05 FT/SEC, MASS FLUX = 1.429 LBM/SEC*FT**2, PARTICLE DIAM. = 3.294 MICRONS, IMPACT ANGLE = 1.002 DEG.

CALCULATED EMPIRICAL EROSION RATE:

15.762 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF .007 MILS AT Z/RT = 22.422

PARTICLE IMPACT EROSION SUMMARY
FROM EMPIRICAL MODEL

Z/RT	EROSION DEPTH (MILS)
9.8728	.00
9.8823	.32
10.4594	.24
10.7189	1.66
11.3736	1.63
11.6495	6.03
12.4797	7.52
13.1945	34.48
13.9092	32.23
15.0482	31.41
16.6254	140.84
17.3424	124.12
18.5287	107.27
19.7505	91.85

20.9566	79.11
22.0234	70.37
22.4221	23.27

PARTICLE IMPACT EROSION MODEL

INPUT DATA

TOTAL EROSION TIME(SEC)= 4.00
PARTICLE DENSITY(LBM/FT**3)= 186.00 TARGET DENSITY(LBM/FT**3)= 120.00 TARGET SHEAR YIELD STRESS(PSI)= 2200.00
FINITE ELEMENT AXIAL LENGTH(MICRONS)= 250. AXIAL PRINT INCREMENT(IN)= 2.55 LAST AXIAL PRINT LOCATION(IN)= 50.94
GAS VELOCITY(FPS) = 10197.64 DRAG COEFFICIENT = 5.00 GAS DENSITY(LB/FT**3) = .00316470

FACTOR= .6782+01 EXPFAC= 2.000

AXIAL LENGTH (IN)	PARTICLE DIAMETER (MICRONS)	PARTICLE VELOCITY (FPS)	INCIDENT FLUX DENSITY (LBM/CU.FT.)	IMPACT ANGLE (DEG)
.000	.12776+01	10109.92	.16122-04	.484
2.153	.12776+01	10172.40	.14857-04	.459
3.123	.16101+01	10171.62	.42082-04	.568
5.667	.16117+01	10237.34	.38973-04	.571
6.262	.20101+01	10216.36	.84765-04	.715
9.534	.20092+01	10291.52	.79853-04	.711
10.791	.25456+01	10263.90	.16353-03	.907
13.677	.25445+01	10322.03	.14997-03	.897
18.177	.25419+01	10401.92	.13164-03	.912
19.761	.33152+01	10340.16	.25341-03	1.213
23.082	.33128+01	10392.08	.23249-03	1.167
28.290	.33086+01	10463.65	.20476-03	1.126
33.611	.33045+01	10527.70	.18140-03	1.084
38.717	.33009+01	10582.49	.16264-03	1.046
43.303	.32976+01	10626.88	.14826-03	1.020
47.439	.32947+01	10663.46	.13695-03	1.029
48.270	.32942+01	10670.44	.13489-03	1.024
48.582	.32940+01	10673.05	.13413-03	1.008
48.650	.32939+01	10673.60	.13397-03	1.005
48.683	.32939+01	10673.89	.13389-03	1.003
48.699	.32939+01	10674.01	.13385-03	1.002
48.703	.32939+01	10674.05	.13384-03	1.002

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CALCULATED AXIAL DISTRIBUTION OF EROSION RATES

AXIAL LENGTH (IN)	% OF PARTICLES PENETRATING DEBRIS LAYER	DEBRIS LAYER VELOCITY (FPS)	DEBRIS LAYER DENSITY (LBM/FT**3)	EROSION RATE (MILS/SEC)	AVE.NO.OF PARTICLE COLLISIONS
.00	98.4	10110.	.00001612	2.2	1
2.55	2.0	10018.	.00002598	.1	3

******* ZERO EROSION RATE CALCULATED FOR 100 CONSECUTIVE STEPS *******

PARTICLE IMPACT EROSION SUMMARY
FROM EROSION MODEL

Z/RT	EROSION DEPTH (MILS)
9.8728	.60
10.1248	0.64
10.5168	.56

FIN

5.3 CASE 3: PIEROS STAND-ALONE CODE

Case 3 shows that the empirical and debris layer models can be used completely independently of the ISPP. If the impacting particle flow conditions are known from another source, or if sensitivity studies are being conducted to determine the effect of a particular particle flow condition on erosion, the conditions may be input directly to the PIEROS stand-alone code within the $DATAIN namelist.

The UNIVAC 1108 control cards and the input for Case 3 are shown in Tables C-7 and C-8, respectively. Notice in Table C-8 that if an axial distribution of impacting particle conditions is to be input, an additional $DATAIN namelist is required for each impact point. However, the $ERODIN namelist is required only once, following the first $DATAIN.

The output format for Case 3 is shown in Table C-9 to have the same sequence and format as the Case 2 output in Table C-6.

@ASG,AX	PIE.	Assign program file for PIEROS Stand-alone erosion code
@XQT	PIE.PIEROS	Execute absolute element PIEROS in program file PIE.
	DATA	
@FIN		
@@		Remote job entry end of file.

Table C-7: UNIVAC 1108 Control Cards for Sample Case 3.

```
SD001 TEST CASE
$DATAIN
RT=3.881,ZWMAX=22.422,SMP=247.7,HPS=1.,
ZW=9.853,UG=9747.,VG=2986.,RHG=.00318,
JMAX=1,UP=9638.,VP=3045.,RHP=1.611E-5,HP=0.,DP=1.277,
$END
$ERODIN
CD=5.,RHOTAR=120.,Y=200.,ST=2200.,XPRINT=2.,TIME=4.,KMOD...
MAXY=4000,
ERMIN=1.,
ISAVE=10,
$END
$DATAIN
ZW=10.649,UG=9859.,VG=2923.,RHG=.00131,
JMAX=2,UP=9756.,9702.,VP=2977.,2994.,RHP=1.433E-5,2.776E-5,
HP=2*0.,DP=1.277,1.782,
$END
$DATAIN
ZW=11.486,UG=9964.,VG=2863.,RHG=.00259,
JMAX=3,UP=9856.,9808.,9750.,VP=2914.,2934.,2958.,
RHP=1.282E-5,2.535E-5,5.035E-5,DP=1.277,1.782,2.314,
HP=0.,0.,0.,
$END
$DATAIN
ZW=12.653,UG=10092.,VG=2785.,RHG=.00227,
JMAX=4,UP=9984.,9936.,9881.,9794.,VP=2836.,2857.,2878.,2905.,
RHP=1.115E-5,2.200E-5,4.333E-5,8.677E-5,HP=4*0.,
DP=1.277,1.782,2.314,3.024,
$END
$DATAIN
ZW=14.964,UG=10296.,VG=2639.,RHG=.00181,
JMAX=5,UP=10189.,10139.,10085.,10004.,9852.,
VP=2703.,2725.,2745.,2771.,2804.,HP=5*0.,
RHP=8.704E-6,1.709E-5,3.351E-5,6.606E-5,1.278E-4,
DP=1.277,1.782,2.314,3.024,4.088,
$END
```

Table C-8: Input Data for Sample Case 3

```
                              PARTICLE IMPACT EROSION IN A NOZZLE EXIT CONE


               SD001 TEST CASE

MASS-AVERAGED PROPERTIES OF IMPINGING  ARTICLES AT Z/RT =   9.855 :
   VELOCITY = 10107.57 FT/SEC, MASS FLUX =   .163 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.277 MICRONS, IMPACT ANGLE =  .501 DEG.
CALCULATED EMPIRICAL EROSION RATE:
        .088 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF        .351 MILS AT Z/RT =   9.863

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  10.649 :
   VELOCITY = 10169.39 FT/SEC, MASS FLUX =   .428 LBM/SEC*FT**2,  PARTICLE DIAM. = 1.610 MICRONS, IMPACT ANGLE =  .574 DEG.
CALCULATED EMPIRICAL EROSION RATE:
        .426 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       1.702 MILS AT Z/RT =  10.691

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  11.486 :
   VELOCITY = 10215.74 FT/SEC, MASS FLUX =   .904 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.010 MICRONS, IMPACT ANGLE =  .725 DEG.
CALCULATED EMPIRICAL EROSION RATE:
       2.053 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF       9.212 MILS AT Z/RT =  11.647

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  12.655 :
   VELOCITY = 10263.88 FT/SEC, MASS FLUX =  1.676 LBM/SEC*FT**2,  PARTICLE DIAM. = 2.546 MICRONS, IMPACT ANGLE =  .908 DEG.
CALCULATED EMPIRICAL EROSION RATE:
       8.528 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF      34.512 MILS AT Z/RT =  13.194

MASS-AVERAGED PROPERTIES OF IMPINGING PARTICLES AT Z/RT =  14.964 :
   VELOCITY = 10339.96 FT/SEC, MASS FLUX =  2.617 LBM/SEC*FT**2,  PARTICLE DIAM. = 3.315 MICRONS, IMPACT ANGLE = 1.215 DEG.
CALCULATED EMPIRICAL EROSION RATE:
      35.336 MILS/SEC, RESULTING IN A MAXIMUM EROSION DEPTH OF     141.544 MILS AT Z/RT =  16.628


                              PARTICLE IMPACT EROSION SUMMARY
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Table C-9: Output for Sample Case 3

FRUM EMPIRICAL MODEL

Z/RT	EROSION DEPTH (MILS)
9.8530	.00
9.8629	.35
10.6910	1.70
11.6472	8.21
13.1941	34.51
16.6277	141.34

PARTICLE IMPACT EROSION MODEL

INPUT DATA

TOTAL EROSION TIME(SEC)= 4.00
PARTICLE DENSITY(LBM/FT**3)= 247.70 TARGET DENSITY(LBM/FT**3)= 120.00 TARGET SHEAR YIELD STRESS(PSI)= 2200.00
FINITE ELEMENT AXIAL LENGTH(MICRONS)= 200. AXIAL PRINT INCREMENT(IN)= 2.00 LAST AXIAL PRINT LOCATION(IN)= 49.39
GAS VELOCITY(FPS) = 10194.13 DRAG COEFFICIENT = 5.00 GAS DENSITY(LB/FT**3) = .00318000

FACTOR= .6782+01 EXPFAC= 2.000

AXIAL LENGTH (IN)	PARTICLE DIAMETER (MICRONS)	PARTICLE VELOCITY (FPS)	INCIDENT FLUX DENSITY (LBM/CU.FT.)	IMPACT ANGLE (DEG)
.000	.20102+01	10215.74	.80519-04	.723
4.529	.25458+01	10263.88	.16325-03	.908
13.498	.33153+01	10339.96	.25314-03	1.215

CALCULATED AXIAL DISTRIBUTION OF EROSION RATES

AXIAL LENGTH (IN)	% OF PARTICLES PENETRATING DEBRIS LAYER	DEBRIS LAYER VELOCITY (FPS)	DEBRIS LAYER DENSITY (LBM/FT**3)	EROSION RATE (MILS/SEC)	AVE.NO.OF PARTICLE COLLISIONS
.00	97.8	10215.	.00008852	17.7	1
2.00	.3	9947.	.00012152	2.3	5
4.00	.0	10101.	.00015451	.9	10
6.00	.0	10162.	.00016525	.1	16
8.00	.0	10190.	.00016525	.0	23

******* ZERO EROSION RATE CALCULATED FOR 100 CONSECUTIVE STEPS *******

PARTICLE IMPACT EROSION SUMMARY
FROM EROSION MODEL

Z/RT	EROSION DEPTH (MILS)
11.4860	.00
12.8654	70.63
12.1420	9.30
12.5266	3.46
12.9732	.58
13.4576	.05

FIN

6.0 REFERENCES

C-1 Nickerson, G. R., Coats, D. E., and Hermsen, R. W., "A Computer Program for the Prediction of Solid Propellant Rocket Motor Performance - Interim Technical Report, Volume III," AFRPL-TR-80-34, April 1981